AIR DEFENSE MODEL REQUIREMENTS DOCUMENT: PHASE I

29 September 1995

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The Air Defense Model Requirements Document (ADMRD) is a planning document for improving the representation of air defense in Army models and simulations in the Army's Air Defense Model Improvement Program (ADMIP). The ADMRD is used to record an audit trail of study requirements, reviews of models and simulations, and reports of model validation pertaining to air defense phases of the ADMIP. This initial ADMRD documents the findings of ADMIP Phase I, which focused on enhancements to the Army's Vector-in-Commander (VIC) corps-level simulation. Two lines of work were pursued during Phase I ADMIP: (1) improving the ability of VIC air defense algorithms to model short range air defense (SHORAD) weapons and command, control, communications, and intelligence (C3I)elements, and (2) developing a linkage between VIC and the Extended Air Defense Simulation (EADSIM), resulting in a VIC-EADSIM model confederation. The ADMRD documents (1) the design of SHORAD improvements to be implemented into VIC in a later phase of ADMIP, and (2) descriptions of ways the VIC-EADSIM confederation can be applied in studies and analyses and limitations to the use of the confederation in studies and analyses.

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AIR DEFENSE MODEL REQUIREMENTS DOCUMENT: PHASE I

29 September 1995

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FOREWORD

The Air Defense Model Requirements Document: Phase I was developed by Vector Research, Incorporated (VRI), Ann Arbor, Michigan for the US Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC), Fort Leavenworth, Kansas, under delivery order 9, Air Defense Model Improvement Program — Phase I, to TRADOC contract number DABT65-92-D-0003. The VRI Cognizant Corporate Officer for the effort was Dr. W. Peter Cherry, the Program Manager was Mr. Michael Farrell, and the Project Leader was Mr. David Thompson. Other VRI technical staff who participated in the preparation of this document were Mr. Reed Davis and Mr. George Antonios. Oversight for TRAC was provided by the contracting officer's technical representative (COTR) for this delivery order, Mr. Richard Calkins.

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CONTENTS

LIST OF EXHIBITS

1.0 INTRODUCTION

This document is the Air Defense Model Requirements Document (ADMRD), a planning document for the Army's Air Defense Model Improvement Program (ADMIP). This is the first edition of the ADMRD, documenting the findings of ADMIP Phase I. This introductory chapter describes the purpose of the ADMRD, an ADMIP overview, Phase I of ADMIP, the development of the ADMRD, and the organization of this volume.

1.1 PURPOSE OF THE ADMRD

The ADMRD is used to record an audit trail of study requirements, reviews of models and simulations, designs of changes to those models and simulations, and reports of model validation during phases of the ADMIP. This volume is the initial edition of the ADMRD, documenting Phase I.

Recording ADMIP model enhancements in the ADMRD is intended to contribute to the use and continued development of Army analysis tools by:

(1) providing a place to record designs for model improvements, and guiding implementation of the models and simulations during successive phases of ADMIP;

(2) providing continuity as ADMIP work is performed over time, thus allowing work to be performed in increments as ADMIP funding becomes available;

(3) documenting the results of the development to assist in later documentation and use;

(4) providing lessons learned in support of later ADMIP phases; and

(5) providing a template to guide the documentation of later phases of ADMIP.

It is intended that the ADMRD be a "living document" that is referenced and added to during all phases of the ADMIP program, and that it maintain a current picture of the Army's air defense-related model improvements.

1.2 ADMIP OVERVIEW

This section presents an overview of the Air Defense Model Improvement Program (ADMIP).

The purpose of ADMIP is to improve the representation of air defenses in Army models, with an emphasis on combined arms models used for analysis, so that the models are:

- applicable to current and anticipated analytic needs;
- consistent in their representation of systems, processes, and input data and in the results within the context of an appropriate range of related model scenarios; and
- capable of addressing analysis issues in joint and combined warfare contexts.

Combined arms models which have been identified as probable subjects of improvement in ADMIP are VIC, TACWAR, EAGLE, and JANUS. In the first phase, efforts were focused on the VIC corps-level campaign simulation.

ADMIP has several objectives. Central objectives are to improve the representation of air and air defense across all levels of modeling and simulation (M&S), and to achieve greater consistency across all M&S for studying the new air threat at all echelons. Achievement of these objectives will provide models capable of providing more realistic M&S for combined arms analysis on functional issues and will improve support by model users to USAADASCH, TRADOC Battle Labs, and other TRADOC schools. Included in ADMIP will be activities to provide an improved, robust air defense environment for distributed interactive simulation (DIS) applications. ADMIP will also include activities to ensure to the extent possible that there will be compatible model methodologies and data structures to facilitate the distributed linkages to applicable AD models.

ADMIP is being pursued as a multi-phase program, with specific tasks occurring in each phase as funds become available to undertake increments of work. To aid in

maintaining continuity in ADMIP efforts over the multi-phase program, the results of each phase will be documented in the ADMRD.

1.3 PHASE I ADMIP

Phase I ADMIP focused on enhancements to the VIC corps-level simulation. Phase I included a review of air defense study requirements in general, and a review of the capability of VIC in particular to meet those requirements. VIC design and development during Phase I focused on two principal lines of work to enhance the capability of VIC to address study requirements:

(1) improving the ability of VIC air defense algorithms to model Forward Area Air Defense System (FAADS) weapons and C3I elements, and

(2) developing a linkage between VIC and the Extended Air Defense Simulation (EADSIM), resulting in a VIC-EADSIM confederation.

During Phase I it was decided that issues related to FAADS systems would be the most likely area in which VIC might be required to examine air defense issues. This was both because of the possibility that FAADS system issues (development, acquisition, employment, etc.) might soon come to the fore in the Army study program, and because of the role of SHORAD systems to the close-in battle and the importance of representing SHORAD credibly in any VIC study of Army system. For these reasons, TRAC model developers felt that the most benefit would derive to the Army by devoting the Phase I ADMRD primarily to FAADS and other SHORAD systems.

Development of the VIC-EADSIM confederation was aimed at improving the linkage between the analysis of theater missile defenses (TMD) and the analysis of corps-level air and ground campaigns. The objective was to do this by developing a prototype of a single tool containing both a high-resolution representation of TMD and other air defenses, and a balanced representation of the ground campaign. The method chosen was

the development of a link between EADSIM and VIC using the Aggregate Level Simulation Protocol (ALSP).

The VIC-EADSIM confederation was developed by TRAC analysts, and the FAADS enhancements were designed by VRI. The model confederation continues under development as of the end of Phase I, and the FAADS design will be implemented in VIC code following Phase I as resources become available.

The remainder of the Phase I ADMRD documents study requirements, the review of VIC, and the FAADS design for VIC. One VIC-EADSIM issue was referred to VRI for inclusion in the ADMRD: the question of the extent to which the VIC-EADSIM might be useable in analysis, and procedures best suited for this use.

1.4 USE OF THE ADMRD

It is intended that the ADMRD be added to in each successive phase of ADMIP. Each chapter will change to different degrees and in different ways.

The study requirements in section 2.0 will probably remain fairly unchanged in subsequent phases, although specific requirements may be added as new air defense studies arise. The present description of study requirements is oriented to issues likely to be investigated with VIC, which is a corps-level model. Should air defense functional area models become the object of ADMIP improvements, it is possible that more detailed requirements related to specific systems could be added to the ADMRD.

The model review in section 3.0 is organized by model, so that additional model reviews can be added to the chapter in subsequent phases of ADMIP.

Section 4.0 documents the FAADS-related improvements to the VIC air defense algorithm, and section 5.0 documents concepts for the use of the VIC-EADSIM confederation in analysis. The intent is for the designs, final implementations, and validation

results of future ADMIP phases to be documented in separate sections to be added to the ADMRD.

1.5 OUTLINE OF THIS VOLUME

The Phase I ADMRD is organized into five chapters, including this introduction. Chapter 2.0 presents the study requirements for improved air defense modeling. Chapter 3.0 reports the findings of a review of the capability of VIC to meet the study requirements. Chapter 4.0 documents the design for improvements to VIC air defense to aid in meeting the study requirements with respect to representing FAADS and other SHORAD weapons and C3I systems. Chapter 5.0 presents concepts for the use of the VIC-EADSIM confederation as a study tool.

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2.0 ANALYSIS OF STUDY REQUIREMENTS

This chapter presents an analysis of study requirements for representation of air defense in the ADMIP models. In Phase I, the analysis was directed at requirements for the use of VIC, including use of VIC in studies of air defense systems and use of the model in studies of other issues for which credible play of air defenses is a necessary background.

The chapter is organized into three sections. Section 2.1 presents an analysis of overall ADA modeling requirements for the use of VIC, including requirements for the representation of both HIMAD and SHORAD systems. Section 2.2 summarizes the operational and organizational concept for the FAADS system, which is the topic of the Phase I VIC enhancements. Additional sections, beginning with section 2.3, will be filled in as additional modeling requirements arise, and as additional models are analyzed in subsequent phases of ADMIP.

2.1 ADA MODELING REQUIREMENTS IN VIC

The following analysis of modeling requirements in VIC was provided by the Studies and Analysis Center (SAC) of TRAC, Fort Leavenworth. The analysis was written by Mr. Ronald G. Magee, Director, Analysis, and includes the contributions of SAC study directors for Corps SAM, PAC-3, and FAAD C2. The SAC analysis is repeated nearly verbatim, with only some minor editorial changes for the ADMRD.

2.1.1 THREAT REPRESENTATION

VIC must be capable of representing a greatly expanded spectrum of air threats than currently portrayed, and in some cases, must represent the support structure as well. These

threats include, but are not limited to, fixed-wing aircraft, helicopters, and tactical ballistic missiles. The primary focus of current interests in ADA analysis is on the TBM threat and the counter-RSTA mission.

2.1.1.1 Fixed-Wing Aircraft Threat

The current representation of fixed wing aircraft is probably adequate for ADA effectiveness evaluation. However, ADA target acquisition processes and terminal weapons effects methodologies should be reviewed.

2.1.1.2 Helicopter Threat

The current representation of helicopters is also probably adequate for ADA effectiveness evaluation.

2.1.1.3 Tactical Ballistic Missile Threat

At the heart of the threat enhancements is the addition of TBM representation in the model. The model must be capable of playing three basic classes of TBMs: very short range (VSRBM), such as FROGs; short range (SRBM), such as SCUDs; and medium range (MRBM). For the VSRBM and SRBM classes, the TELs and support infrastructure must be explicitly portrayed to a depth of 300 km. This must include firing points, hide points, transload points, resupply nodes and tech support nodes, plus the vehicles and missile quantities at those locations. These are low density, high priority targets for blue air and improved ATACMS with APAM warhead. A major study issue will most certainly involve the balance of capability between Attack Operations and Active Defense means of tactical missile defense (TMD), and the impact that will have on ADA missile and launcher requirements. In addition (unfortunately), each launched missile will have to be explicitly

modeled in terms of its three dimensional trajectory, aim point accuracy, and radar cross section. An implicit capability must also exist to represent maneuvering effects (both deliberate and inadvertent), TBM breakup effects, and penetration aids or other terminal countermeasures.

2.1.1.4 Cruise Missiles

A capability to model cruise missiles must also be added. However, it is not envisioned to be a difficult task. A specific flight profile must be modeled, but this should be represented similarly to the fixed wing flight profile (without a return leg). Both high altitude (HACM) and low altitude (LACM) systems must be represented. Incorporation of realistic, dynamic radar cross section for detection is important, especially for LACM, where terrain effects will complicate the detection process.

2.1.1.5 Air-Launched Missiles

The model should represent the capability of fixed-wing aircraft to launch long-range missiles, both anti-radiation missiles (ARMs) and tactical air-to-surface missiles (TASMs), whose flight profiles can be tracked for engagement with ADA.

2.1.1.6 Unmanned Aerial Vehicles

Unmanned aerial vehicles (UAVs) must be modeled in roles that include both contributing to the threat intelligence system and the armed UAV, which should also be modeled. It is important that intelligence UAVs be targets for blue ADA, since interest is currently focused on the intelligence mission of UAVs. UAVs could also be played in the decoy role.

2.1.2 ADA UNIT REPRESENTATION

Each ADA unit must be represented as a command element, one or more individual sensors, and one or more launcher groups. Force structure must be represented for each battalion down to fire unit (platoon) level, and must allow for varying blue configurations of command (launcher farms, distributed command), launcher configuration (mixed loads), and launch tactics (allocations, priorities, fire doctrine) for each fire unit. The ADA force structure should be able to support THAAD, Patriot, Corps SAM (or Hawk), and FAADS units.

2.1.2.1 Sensors

Radars and adjunct sensors must be individually placed on the terrain and be given a primary target line, sector of search (both azimuth and elevation), and probability of detection by range and altitude for each target (dependent on RCS). Radar power distribution must be considered implicitly so that different search sectors may be represented for each type sensor, and thereby effects of cueing from external systems may be portrayed. The representation should include both sensors present at air defense weapon sites and independently operated early warning and cueing sensors. Each sensor will be linked to a specific C2 unit for launch and missile control.

2.1.2.2 C2 System

The C2 system must assign targets, assess engagements, and pass targets to other units, if necessary. Information can be passed among the C2 nodes to develop an air threat picture, and launchers should have the capability of being reassigned, after appropriate delay, to another C2 node in the event the node or its sensor is destroyed. The capability to represent a range of C2 architectures, from fully netted and distributed systems to

site-centered systems (plus any intermediate architecture, such as launcher farms), must be accommodated in the design of the software.

2.1.2.3 Fire Units

Fire units will be homogeneous in terms of launchers, but in the case of Patriot, may have a mix of missile types. Each missile may use passive, semi-active, and/or active seekers to support targeting logic. The units will fire one or two missiles to engage a target. Each missile engagement should be separately portrayed in terms of an intercept point and probability of kill. The capability to assess damage from the engagement must be represented so that another engagement event can be scheduled if the target survives. This is especially true of THAAD engagements of TBMs, which can normally achieve two single-missile engagements and can then hand off the target, if it still survives, to Patriot for a two-missile engagement. Against some TBM threats, Patriot may have the opportunity to fire a single missile engagement following the assessment of a two-missile engagement.

2.1.2.4 Unit Mobility

Mobility of ADA units must be explicitly represented with the sensor movement being independent of the fire unit movement (the sensors are the vulnerable element and must be allowed to make survivability moves). The effect of movement on coverage of the supported force and specific critical assets will be an important issue, regardless of whether the assets were engaged by the threat during the move (i.e., survivability of the assets alone is not a sufficient measure). Doctrinal considerations, such as percent of ADA force moving at any time and radar emission control (EMCON) time, must be represented.

2.1.3 SCENARIO STRUCTURES

Typical scenarios for use in ADA system studies are shown in exhibit 2-1. Missions to be analyzed will include the protection of early entry forces (of other EAC type missions), preparation for decisive operations (protection of the corps tactical assembly area), movement to contact, and support to decisive operations. The latter three could be represented by a single VIC scenario, provided the terrain box will support it.

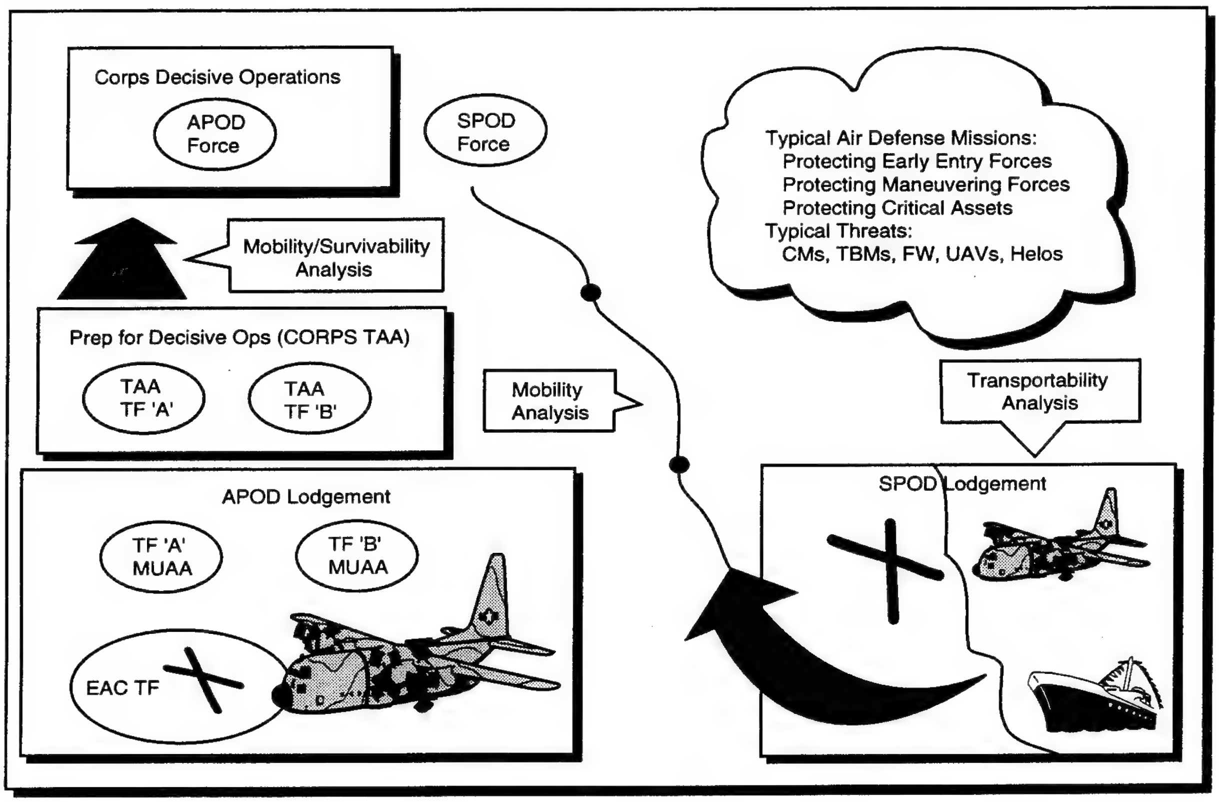

Exhibit 2-1: Typical ADA Scenarios

2.1.3.1 Lodgement (APOD/SPOD)

These scenarios will typically not involve any ground combat, although they could. The purpose of the scenario would be to examine the protection provided to the deploying corps at the congested point of debarkation, and the ability of the deployed ADA force to continue to provide coverage as the units disperse throughout the lodgement area. The high

priority protected assets will be fixed locations (airfields, ports, and command nodes), population centers, and the ADA units themselves, but ability to protect the deploying force will also be a concern. ADA units will normally include THAAD and Patriot or Corps SAM, but probably not FAADS. MRBMs and long range CMs will be included in the threat; VSRBMs and helicopters will not. (Note: A variation of this scenario would be the defense of geopolitical areas, such as Tel Aviv during ODS.)

2.1.3.2 Preparation for Decisive Operations

The purpose of this scenario would be to examine the protection provided to high priority relatively immobile corps support elements. Protection of the corps, although of interest, will probably be irrelevant because of the target priorities for the threat. All types of ADA units and threat systems will probably be available in this scenario, but coverage from THAAD may be limited (may be deployed off the terrain board).

2.1.3.3 Movement to Combat

The purpose of this scenario would be to evaluate the capability of the moving ADA force to provide continuous coverage to the mobile corps force, to assess the impacts of that capability on corps operations (vulnerability, delays, etc.), and to determine the status of ADA capability at initiation of decisive operations. THAAD and MRBMs would not be represented in this scenario.

2.1.3.4 Decisive Operations

This would be the normal corps level scenario typically seen in VIC. Obviously, the purpose would be to measure the contribution of ADA to the corps level battle. Again, THAAD and MRBMs would not be found in this scenario. However, the threat emphasis

would shift considerably to VSRBMs, helicopters, with UAVs being the primary systems of interest.

2.1.4 OTHER MODELING CONSIDERATIONS

The following is a list of general considerations that should not be overlooked in the model enhancement process:

(1) ECM and ECCM must be represented.

(2) Long range RSTA and counter-RSTA support to the battle must be modeled.

(3) Reliability rates for ADA units and threat systems should be considered.

(4) Defensive counter air (DCA) may be handled offline through assumption.

(5) Effects of cueing information from outside the model must be implicitly captured.

(6) Effects of bulk and canister submunitions containing conventional or chemical munitions upon troops, weapons, logistics assets, other infrastructure, and population centers must be represented in the model.

(7) Resupply of ADA missiles must be played and quantity limitations must be a constraining factor.

(8) A preprocessor capability to examine ADA laydown and coverage and threat targeting data (time, location) is essential.

(9) A playback capability to examine the ADA/air threat interactions is useful.

2.1.5 MEASURES OF EFFECTIVENESS

The following list is the essential information which must be capable of being extracted from the simulation runs:

(1) Number of threat systems by type and mission killed by each ADA system.

(2) Number of air threat systems by type that successfully penetrate the air defense system and deliver ordnance (leakers), broken out by those surviving one or more engagements and those not engaged.

(3) Kills and damage caused by each type leaker.

(4) Number and type of reports generated by airborne sensors.

(5) Number of blue ADA systems killed (surviving) over time.

(6) ADA ammunition expenditures.

(7) Number of engagement opportunities.

(8) Size of battlespace by type target; i.e., average range and altitude of successful engagements, and number of engagements above and below a specified "keepout" altitude.

(9) Number of ADA system moves per time block (day, phase of battle).

(10) Fraction of corps units provided HIMAD coverage over time.

2.2 OVERVIEW OF FAADS OPERATIONAL AND ORGANIZATIONAL CONCEPT

Because the representation of FAADS in VIC was the principal design enhancement undertaken in Phase I ADMIP, this section presents a summary of the operational and organizational concept for the FAADS system, including FAADS C3I functions and operation. This section is organized into three sections: the operational plan for FAADS in section 2.2.1, the organizational plan for FAADS in section 2.2.2, and FAADS C3I in section 2.2.3.

2.2.1 Operational Plan for FAADS

The FAADS mission is to protect the force from low altitude aerial threats during force projection operations. Its primary components are the Bradley Stinger Fighting Vehicle (BSFV), Avenger, Man Portable Air Defense System (MANPADS), and FAADS C3I.

Under development in the TRADOC Battle Labs System is a turreted version of the BSFV. Primary targets for the BSFV are RW aircraft and lethal UAVs, thus providing

forward deployed forces with protection from its principal aerial threats and the freedom to maneuver. Avenger provides a counter-RSTA capability, along with protection in the rear areas, to maneuver forces and critical assets; its primary target is the RSTA-UAV, and its secondary targets are Low-altitude Cruise Missiles (LACM) and FW aircraft. MAN-PADS complements these systems by engaging UAVs, LACMs, RW and FW aircraft. The turreted version of the BSFV will be capable of adding LACMs and FW aircraft to its target list.

FAADS C3I provides timely information on the air battle situation and the rapid dissemination of air defense C2 data to FAADS fire units, and to supported unit command posts. Its functions and O&O concept are discussed in subsection 2.2.3.

2.2.2 Organizational Plan for FAADS

In the Heavy Division the FAADS Battalion contains three BSFV Batteries and one Avenger Battery; principal systems in the battalion are 24 BSFV, 24 Avenger, 48 MANPADS and six Ground-Based Sensors (GBS). The battalion is also likely to contain two Commanders Tactical Terminals (CTT), one at the battalion CP and the other with the Avenger Battery. From the current Army Program it would appear that other type divisions will be allocated one CTT each. The Airborne Division battalion will have four batteries, containing 48 Avenger, 32 MANPADS and six GBS or Light/Special Division Interim Sensors (LSDIS). The Light Division battalion will have three batteries, containing 36 Avenger and six GBS or LSDIS. The Air Assault Division battalion will have four batteries containing 48 Avengers, 42 MANPADS and six GBS or LSDIS. Separate Heavy Brigades and Armored Cavalry Regiments will have an air defense battery containing eight BSFV, 12 MANPADS and two GBS.

2.2.3 FAADS C3I

This section describes the functions and operation of FAADS C3I. Subsection 2.2.3.1 describes the functions of FAADS C3I, subsection 2.2.3.2 describes FAADS operations, and subsection 2.2.3.3 discusses additional capabilities which, although not currently planned for FAADS C3I, have in the past been part of FAADS C3I conceptual systems.

2.2.3.1 FAADS C3I Functions

There are four principal functions assigned to the FAADS C3I. These are:

(1) Alerting air defense units and supported units to threatening air situations.

(2) Cueing FAADS fire units.

(3) Disseminating air battle management information.

(4) Exchanging and processing ADA command information.

Alerting is accomplished automatically at the element being alerted, e.g., command post or weapon. Sensor nodes receive air track reports in their area of interest and each report is processed to determine if the parameters satisfy criteria to trigger an alert indication. On activation of the alert indicator, the operator determines if the supported maneuver element should be alerted and, if so, provides the warning via the Army Battle Command System (ABCS) located at the maneuver unit command post.

The FAADS C3I system provides weapon cueing to FAADS fire units. The cueing function provides the fire unit with a display of the air situation in the vicinity with sufficient accuracy to permit correlation of the display information with locally sensed information. Any sensor providing data to the system with an accuracy of 400 meters or better can support the full cueing capability.

Five information items are accommodated by FAADS C3I in the provision of Air Battle Management. These are:

(1) Weapons Control Status — Preestablished rules for minimizing the likelihood of engaging friendly aircraft, i.e. Weapons Free, Weapons Tight or Weapons Hold;

(2) Air Defense Warning — Notifies units of the likelihood of air attack, i.e. red, yellow or white;

(3) States of Readiness — Three states are used for weapons and sensors, i.e. Battle Stations, Standby and Released;

(4) Movement Orders — Permits the AD battalion commander to redistribute his assets, and includes mission and task force changes; and

(5) Sensor Management — Permits FAADS sensor emission control and relocation.

The ADA Command Information function provides information from which commanders will make tactical, administrative, and logistical decisions. It includes such information as unit status, location, battlefield geometry, and NBC alert/warning.

2.2.3.2 FAADS C3I Operations

This subsection describes the operations of FAADS C3I in terms of its control, employment, data exchange, and survivability.

Control. Control is provided at the AD BNTOC, home of the Air Battle Management Operations Center (ABMOC), which is the interface to the Maneuver Control System (MCS) and has links to adjacent FAADS battalions, HIMAD, and joint and allied C2 systems. The ABMOC monitors the division air situation, provides real-time situational awareness, distributes and receives force operations information, and transmits air strike warnings to the force. Supported by the ABMOC, the army airspace command and control (A2C2) element at division, it manages the use of airspace over the division. The BNTOC is the management authority on the sensors and their use and employment on the battlefield by the FAADS C2 modes in accordance with the sensor management plan,

division concept of operations, and the scheme of maneuver. Orders to reposition and radiate or cease radiate will be transmitted from the BNTOC to sensor nodes.

Employment. Sensor C2 nodes are tactically emplaced throughout the division area to optimize volume coverage of the force's area of operations. Sensors will normally be positioned as close to the FLOT as possible and along the flanks, while minimizing exposure to indirect fires. To counter threat location actions, sensors will employ blinking and emission control. The air situation will be broadcast to all fire units when a sensor is not radiating, since it is netted with the other sensors, via EPLRS, and its C2 node will remain active.

Data Exchange. Data Exchange among FAADS C3I nodes depends on the Army Data Distribution System (ADDS), Combat Net Radio (CNR), and the Area Common User System (ACUS). The JTIDS and EPLRS are the components of ADDS which FAADS C3I will use. From the sensor, the information on each aircraft in the sensor track file is passed to the sensor C2 node. This track information is correlated with the track information received from other FAADS sensors through the JTIDS radio located at each sensor C2 node.

The correlated air situation is subsequently filtered and broadcast over the EPLRS radio net to all FAADS fire units and EPLRS-equipped combined arms elements within the sensor C2 node's coverage. These sensor generated tracks provide alerting, cueing, and track identification information to fire units. SHTU/WSD at each weapon system process, filter, and display operational and alerting information, track identification, and cueing information on priority tracks with respect to the location of each fire unit.

Survivability. Survivability of GBS is a function of its deployment, mobility, signature, and hardness. The effects of distance, low sensor side-lobes, and terrain masking will greatly limit the capability of threat LOS DF and intercept systems. Low

probability of DF and intercept. combined with a hasty march order capability, provides a high probability of obviating threat indirect fires. A severe threat may dictate short sensor duty cycles, and rapid and frequent short distance moves. Low probability of intercept technology and blinking with frequency agility can further extend the permissible emission duty cycle.

2.2.3.3 Aerial Sensors and NCTR Systems

The capabilities inherent in aerial sensors and non-cooperative target recognition (NCTR) systems would enhance the value of FAADS C3I in areas where the currently planned and programmed system could not meet potential battlefield requirements, depending on the nature and severity of opposing threats, and the capability of the A2C2 subsystem to meet the demands imposed in likely scenarios. Each of these system types has, in the past, been part of SHORAD C2/FAADS C3I requirements; the current requirement does not include these systems. Both have been dropped for consideration of costs and the nature of post-Soviet threats. However, the capabilities each provides are unique from other FAADS C3I features.

Aerial Sensors. Aerial sensors would extend the surveillance and tracking coverages of a FAADS C3I system. Should the threats change with inclusion of fast movers, or more dense FW attacks, e.g. the Soviet type to establish air corridors, the need to extend FAADS C3I coverages beyond its current limits could become essential to FAADS effectiveness. It was shown in the FAADS II Special Study in 1987 that GBS alone provided near zero coverage beyond the IZB in Germany, which was about 20 kilometers forward of the GSB deployments.

NCTR Systems. Similar threat changes would burden the A2C2 element and established airspace control procedures to the extent that FAADS C3I becomes incapable

of supporting the ABMOC in its role to obviate aerial fratricide, in any way other than placing FAADS in a weapon hold status frequently and at times when its capabilities are sorely needed. A remedy to such a situation could be the fielding and employment of Non-cooperative Target Recognition (NCTR) systems, which provide NCTR identification levels approaching or at unity, as shown in the FAADS II Special Study in 1987.

Impact on VIC Design. Consideration of these factors suggests that sometime in the future there will be a need to analyze the requirements for aerial sensors and NCTR systems in the context of realistic larger unit scenarios. However, because of its low probability, this issue was not considered of sufficiently high importance to be included in the Phase I design.

2.3 OTHER MODELING REQUIREMENTS

This section will be filled in when additional study requirements arise or when additional models are analyzed in subsequent phases of ADMIP.

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3.0 ANALYSIS OF EXISTING M&S TO MEET STUDY REQUIREMENTS

This section presents the analysis of the ability of Army models and simulations to meet study requirements related to air defense. During Phase I, the corps-level campaign model VIC was analyzed, as reported in section 3.1. As additional models are analyzed during subsequent phases of ADMIP, their analyses will be added to this section. It is intended that analyses of air defense models (IFS, COMO, etc.) and force-on-force models (EAGLE, VIC, etc.) will be added.

3.1 ANALYSIS OF VIC TO MEET STUDY REQUIREMENTS

This section contains the analysis of VIC with respect to its capability to meet air defense-related study requirements. The review includes discussions of the model's capabilities, functional deficiencies, and its methodological deficiencies and mismatches with the study requirements. The analysis is organized into the following subsections: 3.1.1, background on the version of VIC analyzed and the basic nature of air defense modeling in VIC; 3.1.2, highlights of the analysis; 3.1.3, outline of the air defense logic; 3.1.4, additional issues concerning the air defense logic; 3.1.5, fire management; 3.1.6, issues related to the engagement of helicopters in the direct-fire logic; and 3.1.7, the representation of air defense units and resources.

3.1.1 VIC BACKGROUND

This section presents some background on the VIC model. It is not intended to act as a complete introduction to VIC — the reader can refer to the VIC Methodology Manual for that purpose. Topics discussed are the version of VIC analyzed (section 3.1.1.1) and a

brief summary of the distinctions among the different air defense modeling methods in VIC section 3.1.1.2).

3.1.1.1 Version of VIC

The analysis was conducted on VIC release 5.0, and included some review of additional air defense code changes made to 5.0 but not given a separate release number. These additional changes included the addition of the facility for the AD module to cause air defense weapons to engage cross-FLOT helicopter units (FL models).

3.1.1.2 VIC Air Defense

There is a difference in the way air defense fires are modeled versus fixed-wing aircraft and helicopters. Engagements of fixed-wing aircraft are modeled in the AD module; these engagements occur when fixed-wing air flights encounter the engagement envelopes surrounding independent air defense units. Engagements of helicopters are modeled in different ways, depending on the location of the helicopter unit. Engagements of helicopters at the front line are modeled in the FL module; these engagements occur when helicopter units engage front line maneuver units. Engagements of cross-FLOT helicopters are modeled with the AD module; these engagements occur when helicopter units encounter the engagement envelopes.

3.1.2 HIGHLIGHTS OF THE ANALYSIS

This section presents highlights of the findings of the analysis of VIC. The principal finding is the lack of any facility for explicitly representing air defense command, control, communications, and intelligence (C3I) processes and systems. The following discussion

describes the need to represent cueing of FAADS engagements and to represent the vulnerability of FAADS C3I.

3.1.2.1 Target Cues

Given the nature of FAADS versions likely to be fielded in the near term, the aspect of C3I that is of most importance for VIC improvements is the ability to provide warning of approaching aircraft to weapons in time to alert the weapons and to cue the detection and engagement process. Earlier FAADS studies and detailed analyses of FAADS performance indicate that early warning can make a very significant difference in the probability of successful engagement compared to uncued engagements. Alerting the search process and narrowing the search sector to an approximate azimuth of approach were found to allow weapons to acquire and engage targets with greater frequency and at longer ranges. No cueing process is currently represented in VIC air defense.

The primary need is to provide information from FAADS sensors. However, for some versions of future C3I systems cues, it could be necessary for the model to represent information which could derive from HIMAD sensors or from surveillance assets such as AWACS or JSTARS.

3.1.2.2 Fire Management

Discussions with air defenders have indicated that existing VIC logic for allocation of AD fires should be adequate for representation of FAADS and other SHORAD systems. This assessments is due to the small envelopes of SHORAD weapons and the consequent reduction in conflicts associated with overlapping envelopes. (On the other hand, the C3 function of controlling allocations of firers to targets may be of concern in future studies involving HIMAD weapons with overlapping engagement envelopes.)

Current VIC logic allows for two extreme cases to be represented. One assumes perfect coordination among air defense sites of each type, and allows no more than one weapon of each type to engage a flight of aircraft at a single time. The other assumes that there is no coordination and that each site selects its own targets, up to its engagement capacity.

Although it does not appear to be a FAADS issue, it is possible that studies of other systems in the future could encounter the need to represent more flexible fire allocation. It is hard to anticipate all possibilities at this time, but a number of alternatives could be added to VIC to account for differences in command and control practices. For example, it would be feasible for code to be added in order choose a fire allocation regine (coordinated versus independent) as a function of the survival of air defense C2 assets within a unit. This would allow fire allocation to differ in different regions of the battlefield.

3.1.2.3 C3I Vulnerability

The vulnerability of the C3I system should be represented. In particular, as C3I elements are attritted by lethal attack, the capability of the C3I system to provide cues to weapons should be degraded. Uncued engagements should bound FAADS weapon performance on the lower end.

This vulnerability could be represented at any of a number of levels of detail. Adding some representation of this vulnerability appears to be more important than providing additional levels of detail about different components of the system (sensors, C2 nodes, communications). Providing hierarchical descriptions of C2 structures and communications connections is probably not required, and might force an unneeded data and analysis burden on VIC users.

3.1.3 OUTLINE OF AIR DEFENSE LOGIC IN VIC

This subsection describes how the overflight air defense calculations are performed in VIC. The description includes background on SIMSCRIPT features used in the model (subsection 3.1.3.1); the top level of the air defense logic (subsection 3.1.3.2); an overview of the next level of logic (subsection 3.1.3.3); and a functional description of key routines (subsection 3.1.3.4).

3.1.3.1 Background on SIMSCRIPT Constructs

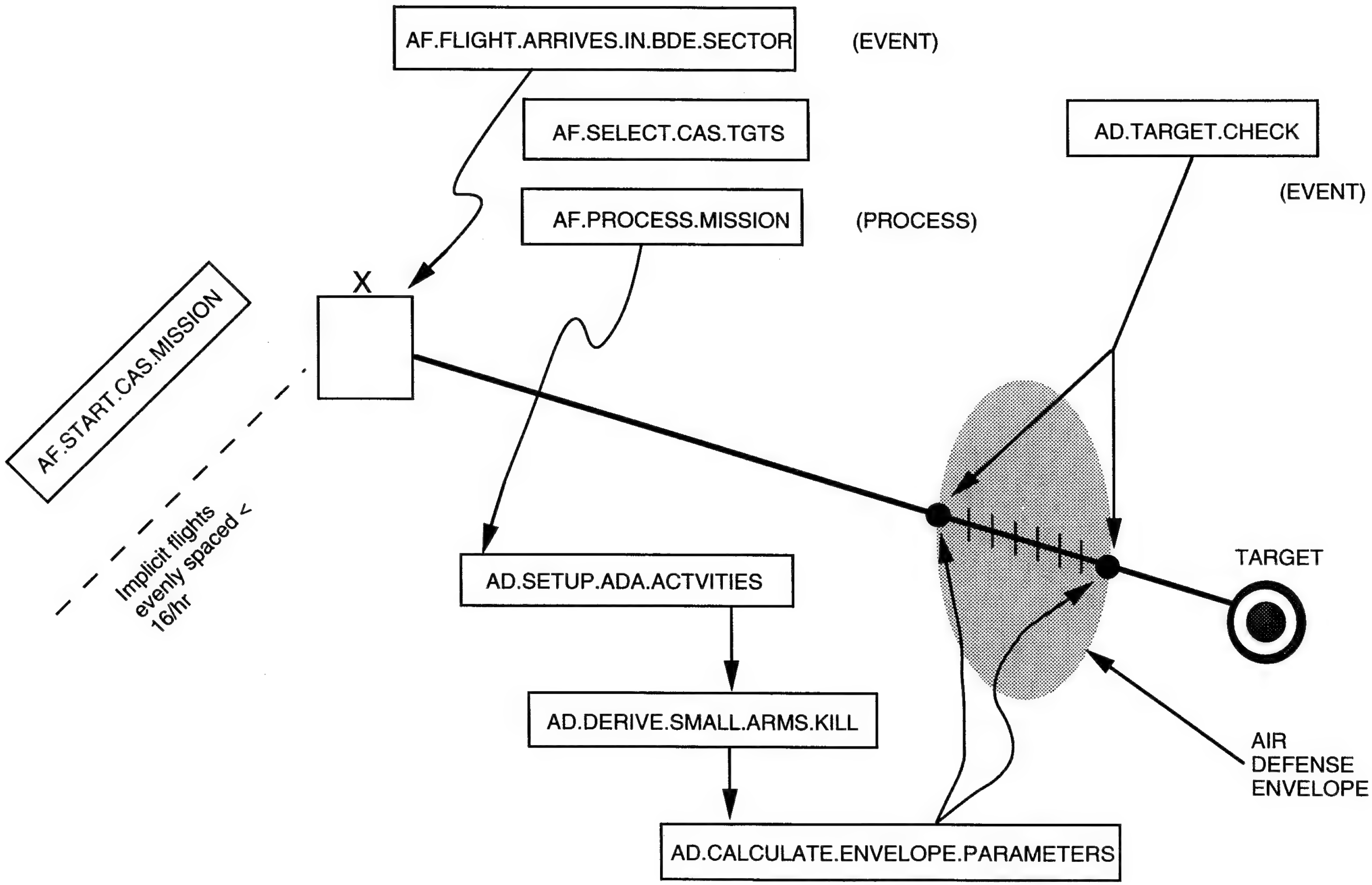
A key to understanding the order of computation is the PROCESS statement. SIMSCRIPT II.5 has a PROCESS statement which evidently provides functionality similar to an EVENT in that it can be scheduled ("ACTIVATEd") but is unlike an EVENT in that it is regarded as existing for a positive duration of time. A PROCESS can be suspended at any point in its calculations by a WAIT statement and will later resume its calculations at the statement immediately following the WAIT statement. VIC makes use of this functionality in the air flight process model.

3.1.3.2 Top Level of Overflight Logic

The AF.PROCESS.MISSION process supervises the ingress, over target and egress phases for a fixed wing flight for both CAS and BAI; this process is the central element in the air flight/overflight air defense interactions. Exhibit 3-1 places this process in the context of air mission processing in VIC.

Ingress is performed by looping over legs of the ingress path; typically, the flight intends to go straight from its current position to a standoff position relative to the target. The intersections of a leg of the flight and the engagement envelopes of air defense fire units are calculated and corresponding air defense envelope entry/exit (AD.TARGET.

EXHIBIT 3-1: FLIGHT PROCESSING LOGIC



CHECK) events are scheduled. The AF.PROCESS.MISSION process is then suspended until such time as the leg of the flight path will be completed — during which interval, the scheduled air defense interaction events will all be processed. At the scheduled time, the AF.PROCESS.MISSION process is resumed and either goes on to the over target processing or performs another ingress leg if necessary (e.g., if the target or its perceived location has moved beyond standoff range).

When an intersection with an air defense envelope occurs for some flight and some fire unit, attrition calculations are executed against all aircraft being engaged by the air defense fire unit: the intersection events denote the points in time when the number of targets in the engagement changes because of entry or exit (rather than attrition). As a result, the time step between attrition assessments is variable and depends entirely on the situation in the model.

The over target phase of the mission process consists of a search for targets and then passes at the targets; the damage done to each target is weighted by the probability of selecting the target.

Egress proceeds much the same as ingress except that there is always only one flight leg back from the target.

3.1.3.3 Overview of the Logic

The list of high level processes, events and routines that VIC invokes in the course of calculating the air defense process follows. The indentation of the list of functions is indicative of calling relationships; however, the list "outdents" semi-independent things like processes to the level of events since they appear to assume an independent existence from the functions which spawned them. (Ellipses indicate that there are other function

calls not shown; parenthetical comments either provide helpful notes or indicate a scheduling of events or activation of a process.)

```
EVENT AF.ALLOCATION.CYCLE (Note:  this is how a BAI flight originates)
     ROUTINE AF.ALLOCATE.BAI.MISSIONS
          ...
          (Activate an AF.PROCESS.MISSION process)
          ...

EVENT AF.FLIGHT.ARRIVES.IN.BDE.SECTOR (Note:  this is how a CAS flight
originates)
     ROUTINE AF.SELECT.CAS.TGTS
     ROUTINE AF.ELIMINATE.THIS.FLIGHT (Note:  the flight is canceled if there
     are no targets)
     (Activate an AF.PROCESS.MISSION process)

PROCESS AF.PROCESS.MISSION
     (Note:  ingress section)
     ROUTINE AD.SETUP.ADA.ACTIVITIES
          ROUTINE AD.DERIVE.SMALL.ARMS.KILL
          ROUTINE AD.CALCULATE.ENVELOPE.PARAMETERS
          (Schedule AD.TARGET.CHECK events)
     ROUTINE AF.SEARCH.FOR.TARGETS
          ROUTINE AF.CALCULATE.PROB.OF.SELECTION
     ROUTINE AF.ELIMINATE.THIS.FLIGHT (Note:  flight is canceled if no
     targets.)
     (Note:  over target section)
     ROUTINE AF.CREATE.TARGET.AREA.CHECKPOINTS
     ROUTINE AD.SETUP.ADA.ACTIVITIES [Note:  this invocation is for the escort
     flight.]
               ... (as above)
     (Activate an AF.SEAD.STRIKE process)
     ROUTINE AF.PERFORM.AIR.TO.GROUND.STRIKE (Note:  this routine is for
     strikes against units.)
          ...
          ROUTINE AF.AREA.DAMAGE
          ROUTINE AF.POINT.DAMAGE
          ...
     ROUTINE AF.PERFORM.AIR.STRIKE.AGAINST.SPECIAL.TARGET (Note:
     this routine is for strikes against roads, bridges, etc.)
     (Note:  egress section)
     ROUTINE AD.SETUP.ADA.ACTIVITIES
               ... (as above)
     ROUTINE AF.ELIMINATE.THIS.FLIGHT

EVENT AD.TARGET.CHECK
     ROUTINE AD.FIRE.CONTROL.MANAGEMENT
```

```
PROCESS AF.SEAD.STRIKE
     ROUTINE AF.SEARCH.FOR.TARGETS
          ROUTINE AF.CALCULATE.PROB.OF.SELECTION
     ROUTINE.AF.CREATE.TARGET.AREA.CHECKPOINTS
     ROUTINE AF.SETUP.ADA.ACTIVITIES
               ... (as above)
     ROUTINE AF.PERFORM.AIR.TO.GROUND.STRIKE
```

3.1.3.4 Functional Descriptions of Main Routines

This subsection describes the functioning of the primary processes and routines of the air defense logic in the VIC AD module.

PROCESS AF.PROCESS.MISSION supervises the calculations for a fixed-wing flight of aircraft flying CAS or BAI missions.

The process begins with the ingress portion of the flight path from its current position. An infinite loop over flight path legs is initiated in which a straight line path from the current position to the target is determined (possibly using the perceived location). If the target is beyond standoff range for the first munition in the flight package, the goal position for the flight is taken to be on this straight path at a distance away from the target which is 95% of the standoff range (if the target is within standoff range, the over target phase begins immediately). Within the ingress loop, air defense interactions are scheduled by invoking routine AD.SETUP.ACTIVITIES (provided that air defense activities are being played and the distance to the target will take more than one second to traverse). The process then WAITs until such time as the flight will be at the end of this path leg (during this suspension a series of AD.TARGET.CHECK events may occur). Upon resumption of the process, the loop continues with the new current position of the flight. The flight will probably be within standoff range and the loop will be exited; however, if it is not

(because the target moved or because the perceived position has been revised), an additional ingress leg-loop will be performed.

Once the flight has reached its goal, a search for targets is performed by invoking routine AF.SEARCH.FOR.TARGETS. If no targets are found, the flight is immediately eliminated (evidently without egress) by invoking routine AF.ELIMINATE.THIS. FLIGHT and the AF.PROCESS.MISSION process is terminated. Otherwise, the process constructs a series of passes for the flight by invoking routine AF.CREATE.TARGET.AREA.CHECKPOINTS (each pass is evidently of length equal to the standoff range of the first munition and parallel to the x-axis). Additionally, the routine AD.SETUP. ADA.ACTIVITIES is invoked for an escort group, if any (making it vulnerable to overflight attrition while the strike flight makes passes at the target); if there is an escort then, an AF.SEAD. STRIKE process is scheduled for immediate occurrence (prior to the loop over passes).

The AF.PROCESS.MISSION process begins a loop over passes made by the flight and immediately suspends execution of the process until the end time of the current pass. When the process resumes, it begins a loop over targets found in the target search routine and invokes the routine AF.PERFORM.AIR.TO.GROUND.STRIKE or the routine AF.PERFORM.AIR.STRIKE.AGAINST.SPECIAL.TARGET; expected damage is computed based on the probability of selection and decremented immediately. When all the passes have been performed, the flight begins its egress.

The egress of the flight is similar to the ingress in that a point of exit (the flight controller position) is selected and a straight line from the current point (the target location) to the exit point becomes the next path leg; however, there is no loop over path legs. The routine AD.SETUP.ADA.ACTIVITIES is invoked again for this path leg and the process is once again suspended until the calculated time of arrival at the end of the leg. Upon

resumption of the process, the routine AF.ELIMINATE.THIS.FLIGHT is invoked to delete the flight and the process is terminated.

ROUTINE AD.SETUP.ADA.ACTIVITIES calculates the interactions (over one leg) of a flight of fixed-wing aircraft with enemy (non target area) air defense assets; manages the allocations of air defense fires.

The routine checks to make sure that the flight has some surviving aircraft and more than a tenth of a kilometer to travel; otherwise, no ADA activities are scheduled.

If airborne jammers are being played, the routine checks for the kind of jammers being carried; if the flight is escorted, the jammers aboard the escort are used to set the jammer index; otherwise, the jammers aboard the attack flight are used (if any).

The routine computes small arms attrition over the given leg of the flight path for both the penetrator and the escort (if any) and decrements the losses from the flight immediately using routine AD.DERIVE.SMALL.ARMS.KILL. If no aircraft survive after this, the routine returns.

It then considers each air defense fire unit on the opposing side which can engage the flight and invoke AD.CALCULATE.ENVELOPE.PARAMETERS to calculate the entrance and exit intersections (in time and space) of the flight's path with the fire unit's engagement envelope. Consideration is given to:

- the status of the fire unit (it must not be "DEPLOYING" or "REMOVED");
- the fire restrictions must be acceptable (fire restrictions appear to be the fractional strength of associated radars or TELs and acceptability is evidently strength greater than .01%);
- the type of air defense weapon ("SHORAD.POINT" and "HIMAD.POINT" are not permitted to fire on overflight);
- if the flight is egressing then the fire unit must be designated to engage egressing aircraft; and
- the entry time must be less than the simulation end time plus 100 seconds.

If intersection points are acceptable then the routine schedules AD.TARGET.CHECK events (one for each of the entry and the exit intersections).

EVENT AD.TARGET.CHECK updates attrition for all flights related to any flight which is entering or exiting some air defense engagement zone.

This event routine first checks to see that some fire unit of the current prototype is scheduled to engage the flight at this time and confirms that the intersection for which it is invoked is valid for attrition (i.e., the intersection is marked "ENGAGEABLE," the fire unit has sufficient capacity to engage the new flight and the flight has surviving aircraft).

It computes the total number of planes within the engagement envelope of the air defense fire unit being entered or exited according to this event. It also computes the time interval since the last time attrition was assessed by this fire unit (saving the current time as AD.LAST.TIME.ATTRITION.CALCULATED for this purpose in the future). Calculations continue provided that:

- there are planes in the envelope;
- time has passed since that last update of attrition; and
- the "heads down" time for the fire unit has expired.

It then computes an adjustment to the firing rate for the fire unit by giving consideration to:

- chemical warfare effects (MOPP) (via call to CH.CHEMICAL.EFFECTS)
- smoke obscuration effects (via call to SM.GET.SMOKE.FACTOR)

The routine then iterates over all intersections of flights with this fire unit in order to calculate the number of shots to be allocated against each air flight (including escorts) and the resulting attrition. First, a jammer degradation factor is determined as

jam.degradation = 1 - jammer.reliability + jamming.factor*jammer.reliability,

(if airborne jamming is being played and the escort or penetrator has jammers, etc. and 1.0 otherwise). Then the firing rate is adjusted yet again for the probability of launch (by

reference to SHOT.TABLE (which depends on aircraft type) and AD.SHOT.FACTOR.TABLE (which depends on the aircraft primary mission type, the side and the ada type)). The number of shots fired is computed from the adjusted firing rate and the time since the last attrition calculation; the rounds are allocated in proportion to the number of planes in the flight. The number of shots at a flight is limited by:

- day/night capability;
- supplies on hand (if logistics being played);
- number of TELs and rails on TELs (escorts are evidently only limited by number of TELs); and
- overkill considerations, i.e., the ratio of the number of target aircraft to the predicted number of kills (this constraint is actually applied after the predicted number of kills is calculated).

The next time that the fire unit can fire (AD.NEXT.ALLOW.ENGAGE.TIME) is computed from the current time, the number of shots fired and the reload time. This value is computed each time a flight exits the engagement envelope. However, it is possible for multiple flights to lie inside the envelope. The code seems to recalculate the value for every flight being engaged at this instant so that only the value associated with the last flight is saved. If the parameter were to be used to decide whether the flight will be engaged in this invocation of AD.TARGET. CHECK then it would appear to be assigned as if reloading was initiated at the end of the last attrition assessment — which is essentially a random point in time.

The predicted number of kills is calculated as the number of shots times the probability of kill (using kill tables, kill factor tables, the jammer degradation factor). Supply usage is updated (via a call to routine LO.UPDATE.UNITS.AMMO.SUPPLIES) and engagements results are written to the post-processor. The next intersection involving this fire unit is addressed in the iteration loop.

Finally, fire control for the fire unit is performed (provided the fire unit has a finite capacity) by invoking routine AD.FIRE.CONTROL.MANAGEMENT.

ROUTINE AD.FIRE.CONTROL.MANAGEMENT assures that only one air defense fire unit of a given prototype engages a flight and that no air defense fire unit engages more flights than its capacity allows. On entry to an air defense engagement zone, the routine creates data structures recording the following:

- an indicator that the flight is currently being engaged by a fire unit of the unit's specific prototype;
- an indicator that this intersection (segment of the flight path) is "ENGAGEABLE;" and
- the number of flights the particular fire unit is now engaging (AD.FLIGHTS. ENGAGED).

On exit from an air defense engagement zone, the routine selects another fire unit of the same prototype as from the flight just escaped: iterating over fire units of the given prototype and, for each such fire unit, iterating on the set of its intersections with flights (these will have been calculated and stored by AD.SETUP.ADA.ACTIVITIES). The selected fire unit (if any is selected) is the first intersecting the given flight such that:

- the flight (at this exit point) is currently within the engagement zone of the fire unit; and
- the fire unit has sufficient capacity to engage the flight (determined by comparing AD.FLIGHTS.ENGAGED for the proposed fire unit to the integer part of AD.MAX.FLIGHTS.ENGAGEABLE * AD.FIRE.RESTRICTIONS).

If an intersecting fire unit was found, the routine schedules an immediate AD. TARGET.CHECK event for the intersection.

3.1.4 Other Air Defense Logic Issues

This subsection adds to the information presented in the preceding overview of air defense logic with respect to the firing restrictions functionality of VIC.

3.1.4.1 Small Arms Fire

This subsection adds some detail for the routine called AD.DERIVE.SMALL. ARMS.KILL. According to the VIC 5.0 documentation (see ad.50, Section 11.2.5: Segment AD-FIVE) the kills calculated in this routine include shoulder-fired air defense missiles (which I would have called SHORADs). A check of an actual VIC data base showed that such missiles (mounted on vehicles) were played as fire units (using the processes, events, and routines described in the preceding subsection). As a result of this part of the VIC review, it was decided to exclude non-air defense weapons from the design improvements. (The small arms lethality model is based on a probability of kill per exposed hour; and, to reiterate the earlier memorandum, all the losses are assessed at the beginning of each ingress/egress leg of the flight.)

3.1.4.2 Fire Restrictions

The fire restrictions parameter in VIC is related to two other attributes of ADA fire units: the number of TELs owned by the fire unit and the number of radars owned by the fire unit. In the AD module, each of these things appears to be a capacity-like attribute of a fire unit rather than a "materiel" part of the unit. However, there is a one-for-one correspondence between these ADA attributes and some front line weapons groups; normal attrition processes which decrement the front line systems also update the AD module attributes (this is discussed further below).

The attribute of an ADA fire unit called AD.FIRE.RESTRICTIONS in VIC is used in the following contexts of the AD module. First, the initial value of AD.FIRE.RESTRICTIONS for each input fire unit is taken to be 1.0 (see AD.LOAD.AND.LIST.AIR.DEFENSE.ARTILLERY.DATA).

The value of AD.FIRE.RESTRICTIONS is decreased as a result of decrements to the materiel in ground units to which the ADA fire unit belongs; the routine AD.APPORTION.WPN.GROUP.KILLS.TO.TELS performs this update and is invoked by a large number of routines which calculate damage effects from air (e.g., AF.POINT.DAMAGE), artillery (e.g., AT.AREA.DAMAGE), direct fire (e.g., FL.UPDATE.MASS.OF.UNIT), and minefields (e.g., MF.ACCOUNT.FOR.MINEFIELD.CROSSING.LOSSES), as well as logistics failures (e.g., RD.DETERMINE.RAM.FAILURES). The damage routines inspect an attribute of a weapon group called FL.WG.DUAL.DEFINED.IN.AD, to see if this weapon group has a "dual" or corresponding AD element defined; if so, the weapon group's fractional damage is passed along to the apportionment routine.

The apportionment routine determines whether the corresponding AD element is a TEL (by inspecting the AD.FU.WPN.GROUP attribute of the fire unit) or a radar element (by inspecting the AD.RU.WPN.GROUP attribute of the fire unit); then, the AD.NUMBER.OF.TELS or AD.NUMBER.OF.RADARS (respectively) attribute of the fire unit is scaled by the complement of the fractional damage (i.e., survivor fraction). The fire restrictions parameter of a fire unit suffers the same fractional degradation that either the TELs or radars of the fire unit suffer.

A similar (although inverse) function is carried out for return to duty effects by routine AD.APPORTION.WPN.GROUP.RETURNS.TO.TELS.

In routine AD.DETERMINE.ATTRITION.TO.VULNERABLE.ROUNDS, the fire restrictions attribute is used to filter out units which lack capacity to engage vulnerable munitions (lack of capacity is evidently a value less than .01% in the AD.FIRE.RESTRICTIONS attribute); it is also used to determine the number of shots available against vulnerable munitions in expressions such as the following one:

SHOTS = AD.MISSILES.READY * AD.FIRE.RESTRICTIONS.

In event AD.TARGET.CHECK, the AD.FIRE.RESTRICTIONS attribute multiplies the prototypical firing rate of a fire unit engaging a flight. This product is the initial value of a firing rate which will subsequently be modified for chemical, smoke, etc., effects — as mentioned in the earlier memorandum).

For the engagement of fixed wing flights, the routine AD.FIRE.CONTROL. MANAGEMENT compares the current number of flights engaged by the fire unit, AD. FLIGHTS.ENGAGED, to the integer part of the following variable:

AD.MAX.FLIGHTS.ENGAGEABLE*AD.FIRE.RESTRICTIONS

The former must be less than the latter if the fire unit is to engage the flight.

The obvious interpretation of the AD.FIRE.RESTRICTIONS attribute in VIC is as a joint probability of availability of TELs and radars (where the fractional damage factors for the TELs and radars is interpreted as probability of survival; this interpretation also assumes that the state of the TELs and radars is mutually independent). An exception to this interpretation is in the routine AD.FIRE.CONTROL.MANAGEMENT, where an integer realization of expected engagement capacity is determined.

3.1.4.3 Ownership of Air Defenses

Every ground unit can own a set of ADA surveillance units and every ADA surveillance unit owns a set of ADA fire units (see the VIC Preamble). However, there are no ground units which *are* the surveillance units, i.e., the code creates SIMSCRIPT entities which are surveillance units but does not check that there is a ground unit entity they correspond to (unlike the "owning unit," which must be an existing ground unit). The documentation (see ad.50, Section 11.2.4, Segment AD-FOUR) states that the surveillance unit flag ("*S*") must be present but is "currently inactive" — implying that the code

may be “unfinished” — a surveillance function may have been intended but never implemented.

3.1.5 FIRE MANAGEMENT ISSUES

The fire management rules in VIC air defense is descriptive of current air defense practices. For HIMAD systems, one fire unit is in range of a target will be given charge of it and no other site of the same type will participate. However, for other systems where there is poor communication linkage, this kind of fire control management would be impossible (e.g., manpad Stingers not supported by FAADS C3I systems).

There are still some aspects of fire management in VIC which could be improved, although improvement of fire management modeling is not as great a priority for SHORAD systems as it is for HIMAD systems. The review did not reveal any attempt to balance the load among ADA fire units in range of a target; the chosen fire unit was simply the first available on a list of fire units. If the same unit gets used until its engagement capacity is reached, then its rounds per target will be diminished.

3.1.6 ENGAGEMENT OF HELICOPTERS

This subsection summarizes the review findings of the VIC code relating to helicopters and the engagement of helicopters by air defense weapons.

Helicopter units in flight can be detected like any ground unit using mass weights of weapons groups in the unit and (evidently) reporting the fractional weight observed. See Document fi.50, Section 10.2.3: SEGMENT FI-THREE gives an example where helicopters (Hinds) appear on the WEAPON PROTOTYPE list for PROBABILITY OF DETECTION tables.

Intelligence data bases, who owns them, who sees them, and how often they are updated are issues entirely specified in input data; see Document fi.50, Section 10.2.5 describing SEGMENT FI-FIVE.

3.1.7 REPRESENTATION OF UNITS AND RESOURCES

This subsection adds more detail about the data structure in VIC related to air defense fire units, surveillance units, ground units and front line weapons groups.

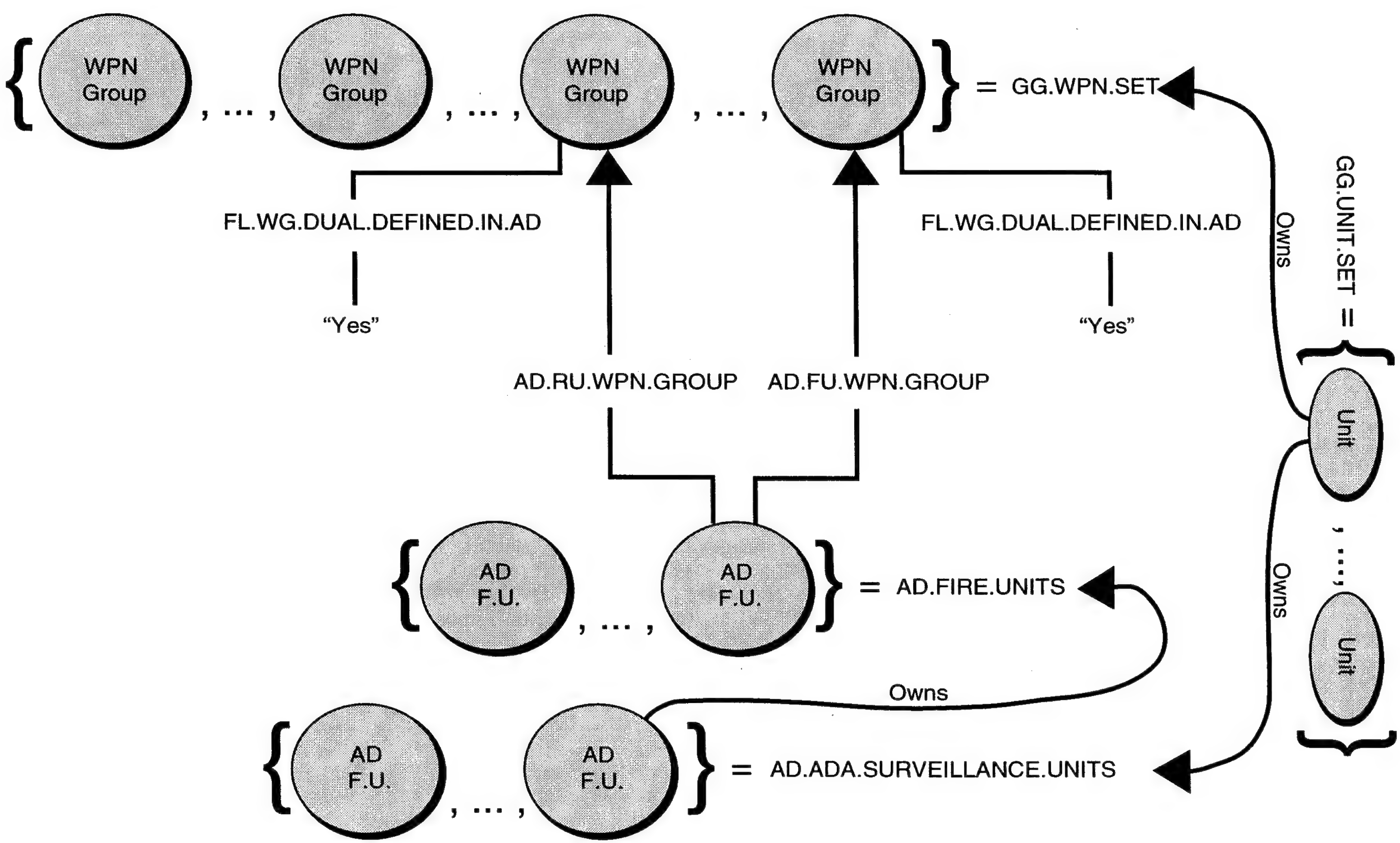
VIC maintains a set of ground units called GG.UNIT.SET; each ground unit in this set may own two other sets: a GG.WPN.SET set and an AD.ADA.SURVEILLANCE. UNITS set. The entities in the latter set may each own a set of air defense fire units called AD.FIRE.UNITS. VIC constructs a mapping between AD.FIRE.UNITS and GG.WPN. SET that enables the effects of damage or repair to weapons groups to affect the air defense functionality of a ground unit. The mapping is represented by the VIC attributes of air defense fire units named AD.FU.WPN.GROUP and AD.RU.WPN.GROUP.

The following description restates the preceding information using some algebra-like equations that helps make the relationships more precise and understandable. Exhibit 3-2 illustrates these relationships. VIC keeps track of all the ground units in a set called

GG.UNIT.SET = $\{u_1, u_2, ..., u_m\}$.

Weapon groups are input for each ground unit from the .FLD file in routine FL.LOAD. AND. LIST.WEAPON.GROUP.DATA; ground units themselves are input from the .GGD file in a routine called GG.LOAD.AND.LIST. UNIT.DATA; and air defense fire units are input from the .ADD file in a routine called AD.LOAD.AND.LIST.AIR. DEFENSE.ARTILLERY. Each ground unit, that is, each $u_i \in$ GG.UNIT.SET may own a set of weapon groups,

EXHIBIT 3-2: OWNERSHIP OF AIR DEFENSE ASSETS



$$GG.WPN.SET(u_i) = \{w_1, w_2, ..., w_n\}$$

and a set of surveillance entities,

$$AD.ADA.SURVEILLANCE.UNITS(u_i) = \{s_1, s_2, ..., s_p\}.$$

Each $s_j \in$ AD.ADA.SURVEILLANCE.UNITS(u_i) owns a set of air defense fire units,

$$AD.FIRE.UNITS(s_j) = \{f_1, f_2, ..., f_q\}.$$

Each $f_k \in$ AD.FIRE.UNITS(s_j) has attributes which look and behave like functions and which identify some weapon group $w_a \in$ GG.WPN.SET(u_i) as the fire unit:

$$AD.FU.WPN.GROUP(f_k) = w$$

and may identify some weapon group w_b as the radar unit:

$$AD.RU.WPN.GROUP(f_k) = w_b.$$

Also note that for each weapon group w which becomes the image of one of these mappings, VIC records that the dual representation exists in an attribute of the weapon group as follows:

FL.WG.DUAL.DEFINED.IN.AD(w) = "YES."

The routine that constructs the mappings described above also checks for correspondence between the front line representations and the air defense representations in terms of kinds of weapons and inventories of weapons. Routine AD.CHECK.FOR.ADA. CONSISTENCY.BETWEEN.FL.AND.AD checks that the air defense weapon's name matched some front line weapon name (this corresponds to the TEL), and that the air defense weapon's radar name matched some front line weapon name (unless the radar name was "NONE"). It then cumulates (over fire units) the number of TELs and the number of radars and compares these sums to the total strength input for the corresponding front line weapon groups.

The mapping described above enables damage (or repair) done against front line weapons to be imaged in the air defense module by propagating the fractional damage (repair) to the appropriate attributes of fire units, i.e., AD.NUMBER.OF.TELS or AD.NUMBER.OF.RADARS and AD.FIRE.RESTRICTIONS.

3.2 ANALYSIS OF OTHER MODELS

More sections will be added as other models are analyzed in later phases of ADMIP.

4.0 PHASE I VIC DESIGN

This chapter contains the description of VIC model designs developed under the Phase I ADMIP program to enhance the representation of FAADS weapons and C3I elements. Designs developed in later phases of ADMIP will be added to the ADMRD as separate chapters.

The description of the VIC FAADS enhancements is organized into the following sections: Section 4.1 presents an overview of the model enhancements that are described in this chapter. Section 4.2 describes how FAADS C3I units and resources are to be added to VIC and how their deployments are to be represented. Section 4.3 describes the representation of FAADS C3I effects in the FL module's representation of engagements of attack helicopters by FAADS weapons in maneuver units. The next four sections deal with enhancements related to FAADS weapons played as independent air defense units in VIC, i.e., air defense weapons not located in maneuver units. Section 4.4 describes the modeling of the detection of aircraft by FAADS sensors, and the representation of information collected by FAADS sensors. Section 4.5 describes potential future enhancements to represent FAADS interfaces to external C3I systems when those interfaces are defined. Section 4.6 describes the modeling of FAADS C2 and the routing of target information by FAADS C2. Section 4.7 describes the representation of FAADS C3I effects in the AD module's representation of engagements of fixed-wing aircraft by FAADS weapons represented as independent air defense units. Section 4.8 describes how the method of section 4.3 also applies to the engagement of cross-FLOT helicopter units. Section 4.9 discusses the need for representation of UAVs and cruise missiles. Section 4.10 presents ideas for potential future enhancements to the modeling of HMAD fire allocation.

4.1 OVERVIEW OF PHASE I VIC DESIGN

To date, the Phase I ADMIP program has been devoted to the development of a modeling design for enhancement of the VIC representation of short range air defense (SHORAD) weapons, especially with respect to representing FAADS, FAADS C3I, and their effects on corps level campaigns.

4.1.1 PHASE I VIC ENHANCEMENTS

The design for Phase I VIC enhancements provides the ability to represent FAADS sensors and FAADS command and control elements and their effects on the outcomes of engagements between FAADS weapons and opposing aircraft, both fixed-wing and rotary-wing. Although intended specifically to allow the representation of FAADS systems, the methods could also be used, if appropriate data is input to VIC, to represent other SHORAD C2I systems.

4.1.2 APPLICABILITY TO OTHER SHORAD SYSTEMS

Although described in the context of FAADS systems specifically, the design presented here is also applicable to the representation of air defense C3I for other systems, both friendly and enemy. (The design can be implemented for both sides in VIC, if desired.) Differences among kinds of air defense weapons and C3I elements can be represented by differences in deployment, employment, and performance data. In particular, users of VIC can input data describing the availability of early warning information to air defense information on both the friendly and enemy sides — i.e., the connectivity of sensors and weapons — and the timeliness and accuracy of this information (in terms of the effects of the information of engagement kill probabilities).

4.1.3 APPLICABILITY TO HIMAD SYSTEMS

Although intended to represent SHORAD C3I, several aspects of the design can be extended to represent HIMAD C2 if the appropriate data are input to VIC. Additional types of early warning sensors can be introduced to represent long range radars and their information can be routed to HIMAD systems, whose performance in engaging fixed-wing aircraft targets can be made a function of the availability of fed-in cues, as the design does for SHORAD systems and SHORAD C3I. (The design already allows for the possibility of using HIMAD sensors as sources of cues to SHORAD systems.)

4.1.4 CODE VERSIONS ANALYZED

The design documented in this chapter was developed from examination of the official TRAC release of VIC 5.0. However, in discussions with TRAC representatives during Phase I ADMIP, it was determined that several improvements to the code had been made subsequent to the original release of VIC 5.0. These enhancements, concerning cross-FLOT helicopter missions, were also reviewed and their impact noted in the design.

4.1.5 STATUS OF IMPLEMENTATION

In addition to a design for SHORAD improvements to VIC, this chapter also presents several additional design ideas for more general improvements to VIC air defense modeling. Because these additional design ideas are not necessary components of the SHORAD improvements, they can be omitted when implementing the SHORAD improvements in VIC. However, their descriptions are included in the ADMRD for the purpose of recording them for reference in the future. They may prove to be of use in two situations: (1) future ADMIP phases dealing with the representation of HIMAD C3I in VIC, and (2) possible future changes in the FAADS C3I and its interfaces.

To clarify the differences between the SHORAD design and the additional design ideas, the contents of both sets of improvements are listed below and mapped to the locations of their descriptions in the corresponding sections of this chapter.

The basic SHORAD improvements deal with both independent AD units and with AD weapons that are part of other units in VIC (and which participate in direct-fire combat). The basic SHORAD design descriptions are as follows:

(1) Section 4.2 describes the addition of resources and units to VIC to represent air defense sensors and C2 elements. It also summarizes the representation of air defense weapons already present in VIC.

(2) Section 4.3 describes the representation of SHORAD weapons in maneuver units, their participation in direct-fire combat against attack helicopters, and the modeling of SHORAD C3I effects on their performance.

(3) Section 4.4 describes the method for representing the detection of opposing aircraft by SHORAD cueing sensors (e.g., GBS and LSDIS), and it identifies an approach for data development. This model pertains to the engagement of fixed-wing aircraft by independent VIC air defense units.

(4) Section 4.6 describes the method for representing the routing of target information to SHORAD. More exactly, subsection 4.6.1 describes the method, and subsection 4.6.2 suggests useful directions for future extensions that exceed the near-term needs of VIC users. This model pertains to the engagement of fixed-wing aircraft by independent VIC air defense units.

(5) Section 4.7 describes the representation of the effects of C3I-provided target cues on the outcomes of SHORAD engagements of fixed-wing aircraft.

(6) Section 4.8 describes how the method described in section 4.3 also applies to SHORAD C3I effects in the engagement of cross-FLOT helicopters.

The future design ideas, which are not essential components of the basic SHORAD improvements, are described in the following sections of this chapter:

(1) Section 4.5 describes potential future interfaces of FAADS C3I with external C3I systems. It includes a general approach to representing the effects on FAADS performance of interfaces with HIMAD C3I.

(2) Subsection 4.6.2 suggests useful directions for future extensions that go beyond near-term needs to represent the flow of target cues through the FAADS C3I system to FAADS fire units.

(3) Section 4.9 describes the need to represent unmanned aerial vehicles (UAVs) and cruise missiles in VIC.

(4) Section 4.10 describes an approach to representing the allocation of HIMAD fires by a class of realistic C2 systems whose performance is intermediate to the two polar opposites available as options in VIC.

4.2 ADDING FAADS SENSORS AND C3I TO VIC

This section describes how FAADS C3I resources and units and their deployments can be represented in VIC with the Phase I enhancements. The description is in two parts: Section 4.2.1 summarizes the existing representation of FAADS weapons, and section 4.2.1 identifies how FAADS sensors and C3I are to be added.

4.2.1 REPRESENTATION OF WEAPONS

The design maintains the current practice at TRAC of representing FAADS weapons to VIC in two ways that are tailored to two different roles:

(1) Avengers are deployed near targets in the brigade rear area. Some are also deployed near protected assets in the division and corps rear areas.

(2) Bradley Stinger Fighting Vehicles (BSFVs) and MANPAD teams are deployed forward with the companies of maneuver battalions.

These choices are not constraints of the model, and each weapon could be played in the opposite manner, if desired. However, these choices represent the judgment of model users as to the most realistic methods available to represent the roles of these weapons. These alternatives involve different methods inside VIC for representing the air defense weapons and their fires at opposing aircraft:

(1) Avengers in the rear area are represented as "independent air defenses", i.e., as separate units identified to VIC as air defense units. This is also the method by which high-to-medium altitude (HIMAD) air defenses such as Patriot and Hawk are represented in VIC. As with HIMADs, the fires of rear area Avengers are computed by the logic of the Air Defense Module. In general, independent air defense weapons fire only at fixed-wing aircraft in VIC.

However, logic was recently added permitting rear area Avengers to fire at rotary wing aircraft on cross-FLOT missions.

(2) BSFVs and MANPADs deployed with forward maneuver battalions are represented as resources belonging to those units. They are not components of independent air defense units, and their fires are not computed by the Air Defense Module. In fact, as resources belonging to non-air-defense units, these weapons cannot fire at fixed wing aircraft in VIC. They can, however, fire at attack helicopters when the unit containing them is engaged with an enemy helicopter unit. These fires are computed using the logic of the Direct Fire Module of VIC.

These are the two basic methods of representing air defense fires in VIC. In discussions with TRAC–OAC representatives, it was decided that these representations would be adequate for future work. These alternatives are retained in the design presented here. (However, no constraints are added that would prevent representing each weapon in the opposite way.)

A third type of FAADS weapon will be of interest in the future. It can be represented in VIC on both the Blue and Red sides via the approaches described above:

(3) A remaining type of short-range air defense system which needs to be represented in VIC are the several ADATS-like SHORAD systems. The US Army has currently in rapid-paced development a turreted version of the BSFV. There are also a number of capable foreign systems, e.g. the Russian 2S6M and the Swedish BOLIDE/BOSAM; the latter system for missiles only employs laser-beam guidance, coupled with radar search and acquisition, whereas the 2S6M employs both surveillance and radars in a gun/missile system. Additionally, foreign means exist to provide advanced C2 to these highly capable foreign SHORAD systems, e.g., the 2S6 can be controlled by the highly mobile Russian Rangir system, which can provide effective C2 for up to 6 2S6M in addition to 4 SA-15, 6 SA-13 and 3 MANPADS. Clearly, these kinds of capability will find their way into Third-World threats in the future. For example, it was reported in Jane's Defence Weekly that during Desert Storm that the Russians attempted, through a third party, to provide the Iraqis with a Rangir air defense command post system. These facts suggest that VIC should be capable of representing such systems on both the US/Allied and threat sides.

4.2.2 REPRESENTATION OF SENSORS AND C2 ELEMENTS

There is no explicit representation of FAADS sensors (GBS or LSDIS) or FAADS command and control elements (AD battalion TOC) in the current version of VIC release 5.0. The methods described in this section can be used to add these elements to a VIC database, so that the effects models described in the following sections can be played. Section 4.2.2.1 presents a discussion of the existing VIC methods for representing sensors and sensor information and identifies the need to introduce a new method suited to the special problems of modeling air defense sensors and the information derived from them.

4.2.2.1 Need for a New Method

Based on review of the VIC logic for the collection, processing, and dissemination of intelligence and targeting information, it was decided that air defense sensors should be modeled using a separate, new method of representation. The reason for this decision was that the existing sensor modeling is more appropriate to the representation of sensors related to ground activities and does not well support modeling of air defense.

(1) The demands on the model user in terms of the effort required to set up the data describing collection, processing, and dissemination of information for the existing methodology are greater than the VIC users and maintainers can afford to devote to FAADS data development and maintenance in most applications of VIC.

(2) The frequency with which the existing logic would need to be executed, in order to model the detection and reporting of fast-moving aircraft would likely have an adverse impact on VIC run time and would not be acceptable.

(3) The existing logic is suited to the time scale of events in the ground war, but it does not seem to be suited to modeling the time scale of events for fast moving aerial targets. This suggests introducing a new and more analytic method, separate from that used for the ground war in VIC. The method should include collection, processing, and dissemination of aerial target information, as well as the command and control of air defense weapons.

4.2.2.2 Sensor Resources and Units

It is proposed that a new category of sensor resource, identified as an air defense early warning sensor resource, be added to VIC. Different types of resources of this category can then be described via input data, so as to allow for differences among such real-world sensor resources as GBS, LSDIS, and other types of air defense sensors. It is important to note that the intent is to represent air defense sensors that are not present at air defense weapon sites; sensors present at air defense sites can already be represented as resources belonging to the sites.

4.2.2.3 C2 Elements

It is proposed that a new category of unit, identified as an air defense command and control element, be added to VIC. Different types of resources of this category can then be described via input data, so as to allow elements at different echelons to be represented. (HIMAD command and control could also be represented in this way.)

4.3 FAADS WEAPONS IN MANEUVER UNITS

This section describes the design for representing FAADS weapons contained in VIC maneuver battalions. As noted earlier, FAADS weapons played in this role (typically, BSFV and dismounted STINGER teams) do not fire at fixed-wing aircraft in VIC, but at helicopter units that engage the maneuver unit that own the air defense weapon. This occurs in the context of the attrition logic of VIC's direct fire (DF) module, which applies to DF engagements between two ground maneuver units or between a ground maneuver unit and an attack helicopter unit. VIC represents fires of FAADS weapons against cross-FLOT helicopter units using a separate method, described in another section of this report.

There are two principal components of the model representing FAADS C3I effects on the engagement of helicopters engaging front-line maneuver units:

(1) representing those FAADS sensors which can contribute information about helicopters to the FAADS weapons; and

(2) representing the effects of this information on the level of performance at which FAADS weapons engage the opposing helicopters.

This method of representation is not entirely new in conception, as it was considered for use during an earlier period in which FAADS issues were of concern, although the methods were never implemented in VIC. This section presents the details necessary to complete the design.

4.3.1 BASIC METHOD FOR HELICOPTER ENGAGEMENTS

Based on discussions among VIC developers from TRAC–OAC and the model designers from VRI, it was decided that, for modeling of helicopter engagements in VIC, it was most appropriate to use an implicit and fairly aggregate representation of FAADS C3I, i.e., an approach which represents C3I effects and does not represent details of early warning or other C3I functions. The method selected has the following basic features:

(1) The performance of FAADS weapons in a maneuver battalion in engaging attack helicopters is a function of the number of FAADS sensors alive and functioning in the maneuver brigade that contains the battalion.

(2) The function is available in the form of data which can be input to VIC.

Section 4.3.2 described the method of representing the sensors, and section 4.3.3 describes the method of representing their effects on FAADS weapon performance.

4.3.2 MODELING FAADS SENSORS AS VIC RESOURCES

If introduced as VIC resources, FAADS sensors are susceptible to the usual processes which govern resource strengths (attrition, reliability failure, repair, replacement, etc.). If sensor units are input separately and distributed throughout the brigade in realistic deployments, their sensor resources are subjected to attrition and other resources realistically and will result in a credible inventory of available sensors over time.

When a brigade-wide count of sensors is needed in VIC, the count can be obtained by iteration over the list of units containing the sensors.

It is assumed that, if FAADS sensors are present to collect target information, sufficient C3 resources are also present to route the information to FAADS weapons in a timely manner. In the modeling of helicopter engagements, there is no explicit modeling of dependence on FAADS C3I.

4.3.3 MODELING THE EFFECTS OF FAADS SENSORS

Based on past studies of FAADS, it is known that the principal effect of providing targeting information to FAADS weapons is to extend the range at which they can effectively engage the targets. This effect can be represented to VIC with by inputting a table specifying how the FAADS weapon range varies as a function of the number of FAADS sensors present in the brigade. The first and last entries in the table should contain:

(1) the minimum engagement range, which pertains when no targeting information is provided to the weapons, and

(2) the maximum engagement range, which pertains when maximal targeting information is provided to the weapons.

The size of the table should be $N + 1$, where N is the maximum number of FAADS sensors contained in a brigade. The value in slot $m + 1$ of the table therefore corresponds to the range when m sensors are operational in the brigade. Values should be interpolated

to the actual number of sensors present in the brigade in question. The dimensions of the table should be AD WEAPON TYPE x FAADS RANGE STEPS x SIDE. This subscripting allows different data values to be provided for different types of SHORAD weapons and for differences between the two sides.

The use of the new table fits within the existing direct-fire algorithm in the DF module. VIC represents DF combat with a differential attrition methodology implemented as the solution of a set of simultaneous difference equations in the DF module. The equations describing the attrition of friendly side weapons are of the general form:

$$dm_i (t) / dt = \sum B_{ji} (t) n_j (t)$$

where the sum is over all weapon types, j = 1, 2, 3, etc. of the opposing side,

m_i (t) = number of weapons on the friendly side of type i surviving at time t, and

B_{ji} (t) = the rate at which each opposing type-j weapon kills friendly side type-i weapons at time t.

The last item is known as the attrition coefficient and is computed in FL from a variety of state information (including the m-vector) and performance and situational data.

Each weapon type has a maximal range (input data) beyond which it does not fire. The attrition coefficients for this weapon type as a firer are set to zero when the range from i to j is greater than the maximum range of weapon type j. For FAADS weapons as firers, the new FAADS C3I data make this range a function of the number of operational FAADS sensors in the brigade area. Application of the new table can be restricted to air defense weapons by testing the index of the weapon type. (The weapon type index possesses enumerated values.)

[Helicopters are treated as special cases when the attrition coefficients are computed. Rates of visibility and invisibility for ground weapons are computed as the product of the average speeds of the weapons and the reciprocal of the mean visible and invisible path

lengths on the terrain where the engagement is fought. Helicopter visibility and invisibility rates are not computed in this way, but are looked up in special data (from the HC module) describing the mean periods of helicopter exposure and invisibility. This allows helicopters to control their periods of exposure according to their use of pop-up (mask-cresting) tactics for target acquisition and weapon employment. Helicopters that can launch from masked positions are treated via data as special cases.]

4.4 DETECTION OF AIRCRAFT BY FAADS SENSORS

This section describes the design for modeling the detection of fixed-wing aircraft by FAADS sensors. (A separate model is already present in VIC to represent detection of helicopter units.) The basic approach is to represent detection events as occurring when an air flight's path intersects a detection envelope associated with a FAADS sensor unit.

The design concept for implementing this approach is to adapt existing logic in the AD module, specifically, logic which identifies the beginning times of air defense engagements by determining the time that an air flight's path intersects the engagement envelope of an air defense site. This logic can be modified to determine the time that an air flight's path intersects a detection envelope centered on a FAADS sensor unit. The information about the intersection (the detection by FAADS) is stored so that it can be used by other code responsible for relating FAADS weapon performance to the nature (and existence) of early warning information.

This section describes where in VIC code the sensor envelope computations can be performed and how existing code can be modified to perform the computations.

4.4.1 EXISTING CODE STRUCTURES

The process AD.SETUP.ADA.ACTIVITIES currently calculates the interactions over one leg of a flight of fixed-wing aircraft with enemy (non-target area) air defense assets. It also manages the allocation of air defense fires. After performing other functions, this routine iterates over opposing air defense units and invokes AD.CALCULATE. ENVELOPE.PARAMETERS to calculate the entrance and exit intersections (in time and space), if any, of the flight with the engagement envelope of each unit. If intersection points exist and if a set of feasibility conditions is met, the process schedules AD.TARGET.CHECK events (one for entry and one for exit). The setup process then WAITs until the time the flight will be at the end of its flight leg and then continues with the new current position of the flight. When the AD.TARGET.CHECK events occur, they update attrition for all flights contained in the envelope at the epoch of entry or exit.

4.4.2 CONTROL OF COMPUTATIONAL FLOW

An efficient way to compute intersections with FAADS sensor envelopes is to utilize the existing logic for weapon engagement enveloped. The process AD.SETUP.ADA.ACTIVITIES could be changed to iterate over air defense sensor units and invoke a routine to calculate intersections of the current leg of the given air flight with the detection envelope around the unit. Because this process goes through periods of activation and waiting as the flight proceeds along its flight path, it might simplify the flow of control in VIC if it maintained control of new air defense computations that are also related to the progress of the flight along its flight path.

4.4.3 COMPUTATION OF INTERSECTIONS

The new code will need to compute the intersection points. It would be efficient to obtain the new code by modifying the existing VIC routine AD.CALCULATE.ENVELOPE.PARAMETERS to calculate the intersections with sensor envelopes, as it currently computes intersections with weapon engagement envelopes. The resulting code might be cleaner and easier to maintain in the future if a separate routine were used for this purpose; the existing intersection code could be duplicated and renamed, and the variable names edited to refer to air defense sensor groups and sensor envelopes.

After the code new computes intersections, it should store information about the intersection event — although in a slightly different manner than information is stored about intersections with engagement envelopes. There are several ways in which this information can be stored. The basic function of the detection information is to provide to record periods of time in it is possible for FAADS sensors to provide. A suggested means of storing the intersection information is described in section 4.4.5.

4.4.4 THE DETECTION ENVELOPE

The detection envelope can be described with a set of data paralleling the structure of existing AD module data for the dimensions of AD engagement envelopes. Mirroring the existing data structures allows reuse of existing code and results in a set of useful shapes for detection envelopes. Logic should be added to the AD module to read the new set of detection envelope data.

4.4.5 STORING THE DETECTION INFORMATION

There are several ways in which the detection information could be stored for use in other parts of the AD module. A convenient and realistic way of doing this involves the

use of an "AD detection event." These events can be scheduled by the logic that computes the entry and exit points of the detection envelope. (See section 4.4.3.) When the entry event occurs, it can set up a variable storing information about the detection — time, time of exiting the detection envelope, detecting sensor, and flight detected. Other sections of code can then examine this table to ascertain if a flight has been detected by a FAADS sensor, or if the opportunity for a detection has occurred. Separately provided data (section 4.6) can describe the outcome and effects of this opportunity.

It would be useful if the entry event also schedules an expiration event to occur when the detection information is no longer of use for cueing air defense weapons. The delay until the expiration event could be an input datum or could be computed from information in the flight path of the detected air flight. The exact value of the expiration time is not critical, since the expiration event is intended to remove the detection information from the table where it is stored, freeing up storage space and purging information that is no longer pertinent. (This supposes that the cue about this air group remains useful to recipients at all subsequent times in the flight's mission.) To summarize, storing the detection information involves use of the following constructs:

(1) An AD detection event, scheduled when the envelope entry and exit times are computed, and occurring at the time of entry to the sensor envelope.

(2) A table in which currently active detections can be listed. Detections are entered into the table by the detection event.

(3) An expiration event to remove detections from the table when they are expired.

Other parts of VIC code can inspect the AD detections table to determine if a particular air flight has been detected by an air defense sensor and which sensors made the detections. Those parts of the code can then model additional aspects of air defense C3I, such as access to the information by C2 elements and routing of the information to air defense weapons.

Alternative methods of representing detection information could be used. For example, the description of the detection could be entered into the detection table by the code that computes the intersection (detection) times. If the detection time and expiration time are stored in the table, other parts of the code can inspect the table and ascertain if a detection is active at the current simulated time. The detection event would then not be needed. However, some logic (e.g, a periodic event) would need to be added to perform "garbage collection," i.e., freeing space by cleansing the detection table of expired detections.

4.4.6 NETTING OF GROUND-BASED SENSORS AND COVERAGE DETERMINATION

A favorable relationship between FAADS engagement rates and threat presentation rates is essential to FAADS effectiveness; this relationship is influenced by several factors, but of considerable importance among these is the level of volume coverage provided by FAADS C3I. One of the salient features of FAADS C3I is the netting of the GBS. This netting allows FAADS C3I to attempt the maintenance of sufficient coverage, while at the same time increasing GBS survivability via sound tactical positioning, movement of sensor nodes, blinking and emission control. Both the levels of surviving GBS and composite GBS duty cycles influence the amount of coverage provided at any given time. Validity in the representation of dynamic FAADS C3I coverage needs to be assured, if a valid representation of FAADS effectiveness over time is to result.

In the FAADS II Special Study, the C2 Sensor Mix Analysis was undertaken by application of the TRAC Imagery Analysis Model (TIAM). Given parameters descriptive of sensor performance, positioning and duty cycles; aircraft flight paths, speeds and radar cross sections; ECM conditions; and environmental and terrain effects, TIAM determines

which aircraft are tracked, when they are tracked (time and range), when they are not tracked, the reasons they are not tracked, the number of simultaneous tracks, and the level of sensor loading. Analysts at TRAC-WSMR have developed a successor model, OT-VIS, which provides improved fit to test data. Use of OT-VIS as a preprocessor for VIC would offer a proven approach to providing valid coverage representation. FAADS engagement rates could be determined on the basis of OT-VIS preprocessed coverage data. Consideration should be given to the detailed design, development and implementation of the logic and data structures in VIC to apply this approach to FAADS C3I coverage modeling.

Two candidate approaches for doing this are (1) represent the coverage areas in detail in VIC, with each sensor possessing its own, unique coverage area, and (2) represent aggregate effects of the GBS sensor assemblage. As the former approach seems to add a considerable data burden on the VIC user, without adding to the validity of results, the latter approach is suggested. One way of representing coverage in an aggregate manner would be to represent each GBS sensor in VIC in terms of an ideal, maximum detection envelope, but to include the coverage probability, derived from terrain analysis, within the value of the envelope's probability of detection that is input to VIC. This probability would then apply to all SHORAD sensors of a given type on a side.

4.5 INTERFACE OF FAADS C3I WITH EXTERNAL C3I SYSTEMS

This section describes interfaces of FAADS C3I with external C3I systems. These systems are in development, and their interfaces with FAADS C3I, if any, cannot be described with certainty at this time. However, these interfaces are potentially important sources of information and may be of interest for future improvements to VIC, although not included in the currently designed improvements. The discussion deals with ABMOC

operations, the Commander's Tactical Terminal, and potential ways of representing these interfaces in VIC air defense modeling.

4.5.1 ABMOC OPERATIONS

ABMOC Operations are conducted from the division air defense BNTOC. As stated in subsection 2.2.3.2 they include:

(1) Monitoring the division air situation through connectivity, via JTIDS and CNR, with the A2C2 element at the division headquarters, and coordinating with and responding to the A2C2 element on air defense weapons control status;

(2) Providing real-time situational awareness to the battalion's fire units and sensor nodes, and to supported units vis MCS;

(3) Receiving force operations information from division, the corps air defense brigade (HIMAD) and adjacent FAADS units via JTIDS and CNR; and distributing this information to subordinate and supported units via EPLRS; and

(4) Transmitting air strike warnings to the force via JTIDS, CNR and EPLRS.

Some of these C2 systems are in continuing development, and the doctrine for waging the information war is continuing to evolve. As this progress goes on, C2 information needs will be refined, as to content and time sensitivity demands; and the communicating filtering, and processing requirements will become more refined and precise. VIC appears capable of dealing with these changes.

4.5.2 COMMANDER'S TACTICAL TERMINAL

The Commanders Tactical Terminal (CTT) continues in development in three versions. Current planning and programming will place it with both HIMAD and FAAD units, ADA brigades and others, e.g. the Joint Tactical Ground Station (JTAGS) and in THAADS units to support TMD operations. It is planned that FAADS battalions will be equipped with the 2 channel, CTT/H-R version. While detailed O&O concepts remain to

be developed, it is apparent that this substantial capability will provide FAADS C3I with direct linkage to HIMAD C3I, which will have the 3 channel CTT, and to JSTARS, AWACS and other airborne sensors of potential value via the Tactical Reconnaissance Intelligence Exchange System (TRIXS) and the Tactical Information Broadcast Services (TIBS). Changes to VIC logic and data structures to provide a flexible capability to represent the effects of these forthcoming intelligence and targeting information capabilities can be made in a straightforward manner by taking the approach of determining, outside the model, the specific information contents, timelines and uses of the information under given sets of tactical conditions.

4.5.3 HIMAD SENSORS

Many issues about the interfaces at the ABMOC and the CTT need to be resolved before these systems are defined sufficiently for purposes of modeling in VIC. The flows of information, information content and accuracy, and the timeliness of the information provided to FAADS C3I are examples of the issues that should be examined as concepts for these interfaces are proposed and analyzed.

Once these issues are resolved, the effects of these systems can be represented to VIC in different ways. Some sources of information (national assets, for example) are outside the scope of VIC, and their information contributions could be reflected without representing the sensors explicitly or, alternatively, surrogate air defense sensors could be played in VIC in the same manner as FAADS sensors, although with different performance capabilities. This might especially be of importance if these modeling approaches are applied to the modeling of HIMAD C3, but also might be of interest if targets such as cruise missiles or UAVs could be told in to FAADS C3I from outside

sources. Some modeling issues would remain to be examined if target information from airborne sensors, such as JSTARS or AWACS, were to be modeled.

The same approach described in section 4.4 for FAADS sensors could also be applied to model information provided to FAADS by HIMAD sensors.

The design described in section 4.4 models detections by FAADS sensors. It can also be extended to model detections by air defense sensors belonging to air defense weapon sites, i.e., the independent air defense units in VIC. The following extensions would be needed to do this:

(1) Data structures would be added to describe the detection envelopes of sensors that are collocated with air defense weapons.

(2) The logic that computes intersections with detection envelopes would be augmented to iterate over air defense units and to compute intersections with their detection envelopes. The resulting detections would be stored in the detection table or events would be scheduled to store the information.

It would also be necessary to model the flow of information from the HIMAD units to FAADS weapons or other users of the information. Methods for modeling information availability are discussed in the next section.

4.6 ROUTING TARGET INFORMATION

Earlier sections of this section describe a design for modeling detections and storing a description of the detections in VIC. This section describes a design for representing the routing of target information from air defense sensors to air defense weapon sites.

4.6.1 REPRESENTING FLOWS OF TARGET CUES

It was decided, on the basis of discussions with the VIC developers and maintainers at TRAC, that it would not be practical or desirable to use the VIC communications module, either in low or high resolution mode, to model the flow of air defense detection

information. The level of resolution of the communications model was felt to be inappropriate, and the data demands of using it for air defenses were felt to be burdensome for VIC users. Instead, a more aggregate approach was selected.

Rather than simulating the flow of information, the design represents the availability of target information to the end users: the air defense weapons. This can be represented by a matrix describing the availability of each sensor's information to each of the air defense weapons on that side. To avoid inputting a large matrix, the matrix can be input and stored in sparse matrix form, e.g., in the form of sublists, or in the form of a list of pairs. Each pair would consist of the ID of an air defense sensor unit and the ID of an air defense weapon unit (one of the independent air defense units currently represented in VIC). The existence of the pair on the list would indicate that information can be routed from the sensor to the air defense weapon in time to have an impact on the engagement of targets by the weapon. (The degree of impact is represented by other data, as described in the next section.)

4.6.2 EXTENSIONS

This model can be enriched to represent other aspects of air defense C3I. Detailed designs are not indicated here, for reasons given below, but the general nature of the extensions is described.

Hierarchical Connections. For example, the IDs of air defense C2 elements could be added to the connectivity description in order to indicate that an information flow is restricted to pass through a particular C2 node on its path from sensor to air defense weapon. This would be appropriate for hierarchically organized air defense systems, but would not be a complete description of systems with redundant connections or with flexible or adaptive connections. For this reason, it is not advised that such a model of C2

connections be added to VIC as a general modeling facility. Instead, it seems prudent to add such connectivity descriptions only as needed for investigation of C2 issues in studies that focus on air defense issues.

C2 Vulnerability. A map of C2 connections, such as that suggested above, would be useful if it were necessary to investigate vulnerability of the C2 elements linking the sensors and the weapons. Information flows could then be cut when C2 nodes are killed.

Allocation of Fires. This model is designed to represent the flow of early warning information, i.e., cues to aid air defense weapons in detecting targets and in accomplishing those detections at longer ranges. Other kinds of effects could also be made dependent on the existence of C2 nodes and links among sensors, nodes, and weapons. Different allocations of fire could apply to the set of air defense weapons controlled by a C2 node in situations when the C2 node is/is not operational. This facility was not designed in detail for VIC for lack of information that coordination of fires is a known problem for FAADS weapons.

4.7 EFFECTS ON ENGAGEMENTS OF FIXED-WING AIRCRAFT

This section describes changes to the engagement effects computations in the AD module to incorporate the effects of the presence/absence of early warning cues received from FAADS sensors. When an engagement is assessed:

(1) Examine the air defense detection table and identify detections, if any, of the current air flight.

(2) Examine the sensor routing data (described in section 4.5) and filter the detections to include only those which would be routed in a timely manner to the current air defense weapon.

(3) If there are any active sensor cues remaining, an input improvement factor is applied to the engagement kill probability. If no cues remain after the filtering, the improvement factor is not applied.

The improvement factor is input as data. The computations are in AD.TARGET.CHECK.

This approach could be enriched to allow for probabilities of detection (combining probabilities of detection of multiple sensors, or decaying detection probabilities as they stale over time).

4.8 CROSS-FLOT HELICOPTERS

Recent enhancements to VIC release 5.0 enable air defense units contained in maneuver units to engage attack helicopter units on cross-FLOT missions. These air defense fires occur if a direct-fire engagement occurs between the helicopter unit and the unit containing the air defense weapon. The results are computed by the FL module with the standard VIC direct-fire algorithm.

It is desirable to represent the effects of FAADS C3I (and other SHORAD C3I) in these engagements of cross-FLOT helicopters. Because these engagements are assessed using the same method as any other engagement between a maneuver unit and a helicopter unit, the SHORAD C3I enhancements to the FL module, described in section 4.3, also apply to cross-FLOT helicopters. No additional enhancement appears to be needed.

It was decided during discussions with TRAC's VIC developers that air defense engagements of helicopters would be represented only as occurring at those times when helicopter units engage in direct-fire engagements with maneuver units. As is currently the case, VIC will not use the AD module to represent fires of weapons in VIC's independent air defense units against helicopter units

4.9 LOW ALTITUDE CRUISE MISSILES AND UNMANNED AERIAL VEHICLES

LACM and UAV, both lethal and RSTA, will be challenging targets for FAADS, with respect to acquiring these targets and maintaining track for sufficient time to engage them effectively. LACM acquisition can be affected by terrain masking to GBS, and the

UAV will present radar cross sections which are very small and flickering. With no aerial sensors as part of FAADS C3I, cueing for acquisition may have to be aided from other sensors, such as JSTARS for the LACM, and JSTARS or HIMAD sensors for the UAV. The maintenance of effective track will probably require a firing doctrine of attempting engagements of a single target from multiple sites. The valid representation in VIC of these engagements will require detailed results from high resolution models and/or DT/OT or FDTE for engagements of:

(1) MANPADS and BSFV vis-a-vis LACM;

(2) Avenger vis-a-vis RSTA UAV; and

(3) Avenger, MANPADS and BSFV vis-a-vis lethal UAV.

These results should be inclusive of cueing and acquisition information and data as to the means and techniques employed, cueing ranges and timelines, and the distributions of the times to acquire. Careful analysis and input of the foregoing data should enable valid representation of engaging LACM and UAV in VIC, using the existing air defense logic with the FAADS weapon and C3I enhancements described in this document.

4.10 FIRER-TARGET ALLOCATIONS

This chapter's design for VIC enhancements has dealt mainly with representing FAADS weapons and C3I elements and with representing the effects of cueing weapons to the approach of potential targets. No enhancements related to fire management in general, and to allocations of firers to targets in particular, have been designed. The exclusion of firer-target allocation issues from the design is appropriate for enhancements limited strictly to the modeling of SHORAD weapons and C3I. That is, no significant changes in SHORAD firer-target allocations are anticipated because of FAADS C3I, apart from

increases in the frequency of target engagement due to the receipt of early warning cues and greater weapon availability arising from improved management of SHORAD assets.

This is not to say that firer-target allocation issues are not of interest for SHORAD system. Where SHORAD weapons are densely deployed with overlapping engagement envelopes, it is possible for multiple SHORAD systems to engage the same target. In general, procedures for managing problems of overkill and wasted ordnance in SHORAD systems can be represented in VIC as it presently stands. (For example, in the case of SHORAD systems represented as independent AD units in VIC, users can position the systems and orient their engagement envelopes to represent realistic assignments of engagement volumes.) However, as FAADS C3I does not appear to affect SHORAD fire allocation, no changes to VIC are required.

The situation will be different if improvements to the VIC representation of HIMAD are undertaken in the future. Greater volumes of overlap of engagement envelopes are possible for HIMAD systems, making deconfliction of opportunities for multiple firers to engage the same target an issue of importance for HIMAD C3I systems. Varieties of methods are in existence now (and more contemplated for the future) for HIMAD systems to control the assignment of firers to targets, prior assignments of priorities and responsibilities to HIMAD weapons prior to engagement and via dynamic allocation of targets and firers during engagement. VIC already possesses logic representing extreme end points on the spectrum of control schemes: (1) uncoordinated fires by independently acting fire units and (2) perfectly coordinated fires by fire units allocated such that an air flight is engaged by no more than a single fire unit at a time. Intermediate C3 systems, providing allocations better than independent fires, but falling short of perfect coordination, are not explicitly represented in VIC.

Fire coordination is an issue in massive raids in which efficient use of air defense ordnance becomes important. In these situations it becomes important not to expend all HIMAD ordnance (across the set of systems defending an area) against a single wave of attackers, so that the set of defenders does not leave itself vulnerable while simultaneously reloading all or most of the defenders' launchers. Although massive fixed-wing aircraft threats are not components of current planning scenarios, much importance is being attached to the UAV, cruise missile, and TBM threats. The possibility of massive numbers of such systems, or successive dense pulses saturating defenses locally, brings attention to the need for representing HIMAD C3 procedures.

Although HIMAD C3 was not the topic of the present effort, it seems prudent to record the kinds of solutions that the Phase I investigators believe would best support the representation of HIMAD systems lying between the extremes. Different kinds of solutions appear to be appropriate for C3I that dynamically allocates firers to targets during an engagement and C3I that imposes constraints on the target selection process.

(1) Concerning dynamic procedures for allocating firers to targets during the occurrence of a raid: It would be difficult to anticipate all possibilities ahead of time. This probably requires tactical rules to be written into the air defense algorithm and tailored to the specific C3 systems represented.

(2) Concerning procedures which do not explicitly assign targets, but which constrain the conditions for making allocations: These could be assigned before a raid and could also be modified during or between raids. Of particular interest are procedures used by US air defenders to meter the expenditure of HIMAD ordnance. Discussions with air defense analysts and operational personnel reveal that the current procedure for dealing with the possibility of massive raids involves the management of the engagement status of individual fire units. Prior to a raid, the set of fire units is partitioned between sets assigned "weapons free" and "weapons tight" statuses. Weapons in the free status engage the first targets to enter the defended space. The C3 element can then reallocate weapons statuses, e.g., switching the "free" assignments to "tight" and vice versa. The first set of defenders can reload their weapons while the second set is already loaded and ready to engage a second wave, should one occur during the reload period.

The latter procedure could be represented in VIC. For example, HIMAD fire units could be assigned individual time schedules by the model user, with the schedule specifying the times at which each unit switches weapons status. Alternatively, the user could partition the set of fire units into two sets, with a programmed rule switching statuses according to ordnance expenditures and load status.

5.0 USE OF VIC–EADSIM IN ANALYSIS

This chapter discusses concepts for the use of VIC–EADSIM confederation as a study tool. Following a discussion of the nature of the problem in section 5.1, this chapter presents suggestions for: assessing the actual extent to which the problem applies to the confederation (section 5.2), testing sensitivity of outcomes to individual events (section 5.3), reviewing and smoothing model results (section 5.4), obtaining experimental estimates of variability of results (section 5.5), the possible need to achieve control over some of the randomness in a run (section 5.6), and some special cases which might be simpler to analyze (section 5.7).

5.1 PROBLEMS WITH THE CONFEDERATION IN ANALYSIS

VIC is deterministic model; it produces a single campaign history output for a fixed set of input values. EADSIM is Monte Carlo in nature. It makes random number draws to determine the outcome of a number of events (e.g., kill/no kill outcomes when AD missiles intercept aircraft and TBMs). The inclusion of EADSIM allows the confederation to be used as a Monte Carlo model, and it appears that many study applications would call for the confederation to be used in a Monte Carlo way. However, for some uses it may be possible to use only a single replication for a set of study runs and to avoid the problems of replicating runs. These possibilities are discussed in this chapter.

The problem arises because of the Monte Carlo nature of EADSIM and the resources required to produce a single replication (run) of the VIC–EADSIM confederation. The resources consumed in generating confederation runs include both the compute time and the user effort to inspect the output and judge its reasonableness. Because of the complexity of both VIC and EADSIM, it is not possible to anticipate all possible

contingencies within the code, and it is necessary for analysts to inspect their simulated combat histories for reasonableness, rerunning cases when necessary.

Monte Carlo models such as EADSIM (and the VIC–EADSIM confederation) are generally used in analysis as the means to obtain simulated experimental outcomes. These outcomes can then be analyzed using techniques of experimental statistics. For a fixed set of inputs, the outputs of a set of replications can be analyzed as a set of samples obtained from a fixed set of experimental conditions. For these reasons, it is not clear that it will be practical to use the confederation as a Monte Carlo tool in a straightforward manner (generating uncontrolled replications to be analyzed as experimental samples). This chapter examines some possible solutions. These are:

(1) Buy lots of machines and run a replication on each with a different initial random number seed.

(2) Experiment with the confederation until a "reasonable" behavior of the EADSIM side is achieved. Then, constrain EADSIM to run this case in all VIC variants.

(3) Set-piece missile attacks preceding the simulated ground combat could be assessed offline and the results fed into VIC. This is a special case that does not call for the use of the confederation, just the two models run separately.

5.2 ASSESSING THE MAGNITUDE OF THE PROBLEM

The first issue to be investigated should probably be to determine if the Monte Carlo nature of EADSIM is actually a problem. That is, do we know that there will be a great deal of variability in campaign outcomes due to variability in outcomes from EADSIM?

It is not a priori obvious that this will be a problem. It is possible, since multiple threat elements (e.g., multiple TBM volleys) are normally played in a run, that EADSIM processes will tend to lie near a central value influence on VIC ground campaign processes (the law of large numbers). On the other hand, it is conceivable that the confederation could be sensitive to changes in certain key events (e.g., a single TBM leakage leading to

the loss of a key asset). It would be useful to know which situation obtains (or if both can obtain in different situations).

If this information were known, it would be possible to compare the variability caused by EADSIM replications to the variability produced by deterministic VIC processes. There are two kinds of processes that contribute to variations in VIC outputs: intended variations in output due to systematic changes in inputs, and unintended variations in output due to structural variance.

As a first step, it would be useful to run an experiment in order to determine the magnitude of variability of output of the confederation that arises when different sequences of random numbers are drawn in EADSIM. The resulting variability could then be compared to the variability in VIC outputs that have historically resulted when VIC is run alone as a study tool. That is, it would then be possible to see if the added variability due to sampling in EADSIM is only "noise," or if it obscures the systematic responses in VIC output that are normally observed in standalone uses of the model.

It should be recognized that VIC, even though it is deterministic, can contribute to variability of results. VIC and other complex campaign models are subject to structural variance, which is the occurrence of counterintuitive results (e.g., non-monotone responses to changes in inputs) associated with correct operation of the model. The usual practice in studies is to review the output of every run and to rerun those cases which exhibit unacceptable behavior. (This is done to detect other problems — data errors, inappropriate decision rules, etc. — in addition to structural variance.) However, experience indicates that not all structural variance can be "smoothed" out by the intervention of model users. Consequently, if the "noise" contributed by EADSIM replications is of a small enough magnitude, that "noise" should not be viewed as contaminating run results to any more

than VIC variability is viewed in that way. It might be reasonable to accept such levels of variability, and to screen out only those variations that are of a troublesome magnitude.

Complex models like VIC can also display a great deal of "militarily appropriate" variability in results when some inputs are varied around near critical threshold values (e.g., changing the number of armor and mech battalions available to commit to a critical deep maneuver operation). This variability can be undesirable if it represents the occurrence of an atypical situation.

5.3 SENSITIVITY TO INDIVIDUAL EVENTS

If the experiments described in the preceding section were to indicate that EADSIM contributes a significant amount of variability into confederation outputs, at least for some scenario of interest, the question arises as to the nature of the events causing the variability. If the events causing the variability can be identified, it might be useful to take some action to add constraints to the model to control the occurrence of the event, so as to allow systematic runs conditions conditioned on the occurrence and non-occurrence of the critical event. For example, it would be useful to know if leakage/non-leakage of a single TBM could cause a major bifurcation in the course of the campaign, or if there are scenarios of interest in which this occurs.

To determine if this kind of event occurs, it would be more convenient to begin the investigation with runs using EADSIM alone, rather than using the whole confederation. The goal would be to determine the probability of critical events, i.e., known to have strong influences on the outcome of the ground campaign. If such events are not known a priori, the investigation could focus on suspect kinds of events, e.g., leakage of chemical warheads that shut down a port, delay the advance of critical arriving units, or destroy a critical command and control node. Alternatively, critical events could be identified via

experiments using VIC alone (removing critical assets, delaying force arrivals in theater and movements to contact, etc.).

5.4 SELECTION OF A SINGLE RUN FOR ANALYSIS

It is not certain that such critical events will exist in all scenarios of analysis interest. One might wonder whether it is necessarily true that an individual event could cause a major bifurcation in the ground campaign. The hypothesized existence of critical events in the TMD battle might be considered questionable in scenarios involving multiple TBM attacks, which is probably the majority of scenarios of real interest to analysis. The finding could plausibly be that results are sensitive to cumulative results of raids, rather that to individual missiles or to individual events involving the missiles and the weapons intercepting them. Diagnosis of runs performed on realistic scenarios could help to determine the nature of the sensitivity.

This investigation could potentially impact the way the confederation is used in analysis. In particular, if a number of penetrators need to get through in order to have a significant impact on the course of the campaign, is more than one run necessary? It would be useful to know if a single realization could be chosen or designed to produce a central value result that is typical of the most likely or most typical realizations. Experiments could be performed with VIC alone (simpler than using the confederation) to investigate the ground war impact of losses of selected targets and combinations of targets. If it appears that a single realization of the ATBM or anti-air battle suffices, the procedure in conducting study runs could be simplified. In this case, the procedure in a study could be to identify a "typical" EADSIM realization by running a number of cases, selecting the most representative one, and then using only this realization in conjunction with VIC.

Users of both models engage in critical reviews of run results and revisions of runs to maintain realism ("smoothing"). Reviewing each run makes it difficult to generate large numbers of Monte Carlo realizations needed to support statistical arguments. However, it does suggest that confederation output will be subject to a great deal of scrutiny, and that it might be possible to exercise some control over realizations of the campaign. In this case, it becomes necessary to devise the right diagnostic outputs and to introduce enough input "knobs" to allow users to control the occurrence of specified, critical events.

A problem with this approach is that different initial conditions, as well as feedback between the models, can cause random number draws in EADSIM to occur in different orders and at different frequencies. Then it would be hard to know how to assign elements of a preselected random number stream to draw events in EADSIM. In this case, a model user might need to impose a very careful and elaborate intervention in the model in order to control the random number stream in a useful way. However, this might be a very elaborate undertaking for a large model like EADSIM.

5.5 EXPERIMENTAL ESTIMATES OF VARIABILITY

Another kind of experiment could examine the variability of results of the VIC–EADSIM confederation when both models are included. Such an experiment might be desirable in order to see if the feedback between the two models leads to sensitivities that separate running of VIC and EADSIM might not reveal. In addition, it might be easier from the experimenter's point of view to perform a brute force experiment, rather than trying to diagnose individual events and hypothesize interactions between the models.

The idea is to run a large number of replications of the confederation on a sample data set. It would be useful to do this for an experimentally useful number of runs, even at the expense of less analyst review and "smoothing" of the results. If several machines

were available, multiple copies of the confederation could be left to run simultaneously overnight from different random number seeds. A variant of the experiment would be to run with EADSIM alone, in order to see the variability in TBM impacts and intercept results.

5.6 CONTROL OF REALIZATIONS

What if the user of the confederation needs to cause certain critical events to occur — as might be necessary if their non-occurrence leads to a completely different kind of war? This kind of "smoothing" is familiar to users of corps and theater-level campaign models such as VIC and VECTOR-3. It is not clear that the right "knobs" exist in EADSIM as it stands now to support such user intervention. If the models are to be used in this way, the appropriate controls need to be identified.

But how do we know which variables and random number draws to constrain in order to force the occurrence of an event? We might diagnose the causative pathways in a certain run, but not know exactly what to do if the initial conditions are changed. That is, maybe we could control the course of events in a baseline run but not in an excursion.

The problem is that the introduction of an excursion can cause all kinds of changes in the course of the campaign and, as a result, different sequences of events and associated draws of pseudo-random variables could occur. Also, feedback to VIC could cause legitimate changes in the course of the ground war, and feedback to EADSIM, etc.

The resolution to this problem may be simply to force certain effects to occur, even if the antecedent events do not occur — e.g., simply force a TBM to impact on a target at a given time, or simply assess target damage at that time regardless of the presence of a TBM.

Consider a run in which we wish to constrain a critical event from happening. What if the run is designed to prevent the occurrence of the event? (It may be a run that adds a new level of capability to the defenders — a level of capability high enough to prevent TBM impact on a critical asset.) Should we force the event to occur, even if it is now a very unlikely event?

5.7 SET-PIECE ATTACKS

Some interesting cases may be simpler to study than is suggested in the preceding discussion. For example, model and use would be simpler in cases where the EADSIM scenario is restricted to a set-piece TBM attack and no other air activities to be simulated in EADSIM. These simpler cases could be analyzed offline and the results input to VIC in terms of the effects of the attack on blue assets. Such simple cases would not require the use of the confederation and could be done offline. Cases involving multiple waves of attack and more complex interactions between blue air defense and red air and TBMs require consideration of the issues discussed in the preceding sections of this chapter.